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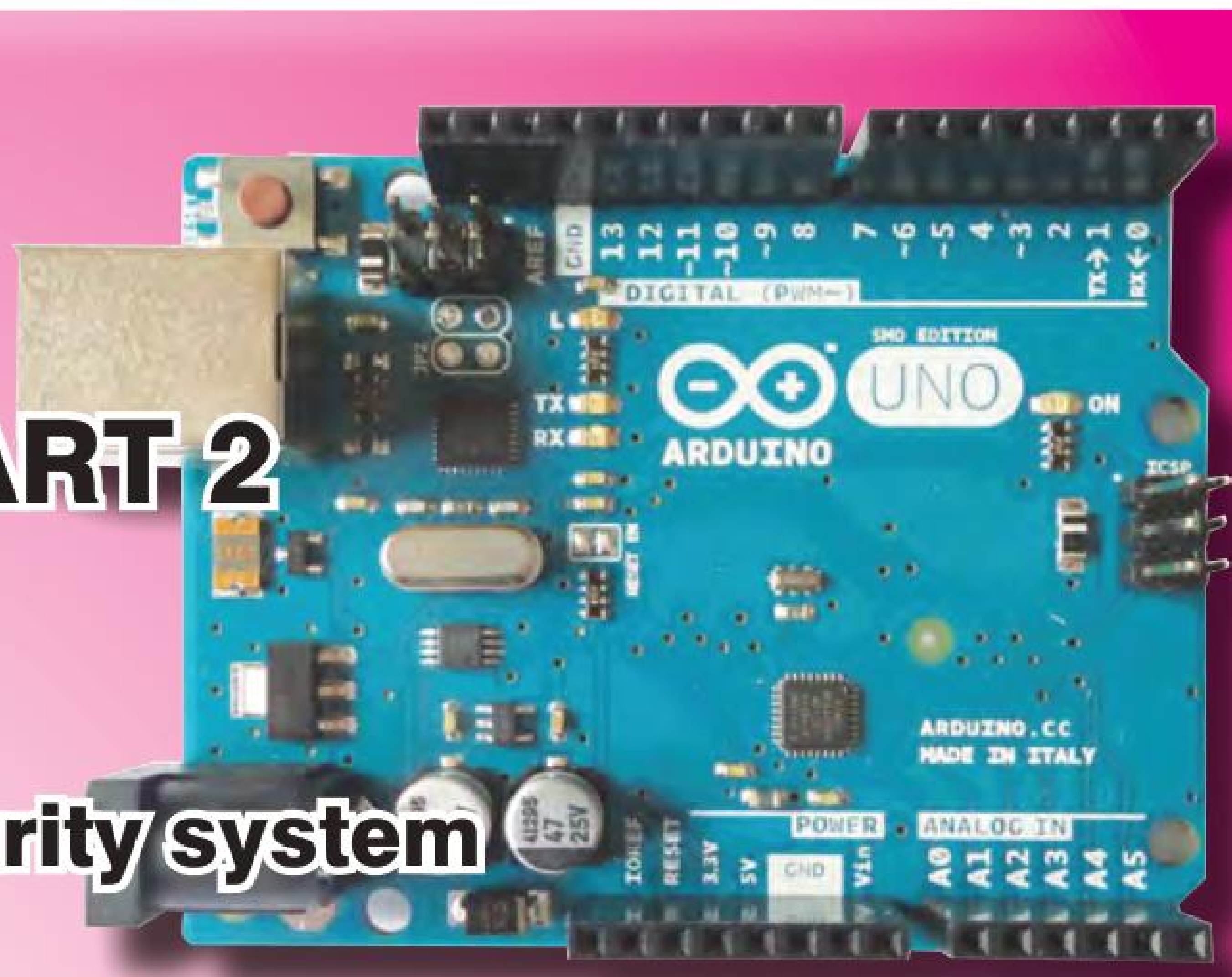

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Assembled with ZIF socket Order Code: AS3149EZIF - £74.95

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*Assembled Order Code: AS3123 - **£39.95***

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*Kit Order Code: 3081KT - **£16.95***
*Assembled Order Code: AS3081 - **£24.95***

PIC Programmer Board

Low cost PIC programmer board supporting a wide range of Microchip® PIC™ microcontrollers. Serial port. Free Windows software.
*Kit Order Code: K8076 - **£29.94***

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PIC Programmer & Experimenter Board with test buttons and LED indicators to carry out educational experiments such as the supplied programming examples. Includes a 16F627 Flash Microcontroller that can be reprogrammed up to 1000 times. Software to compile and program your source code is included. Supply: 12-15Vdc.
*Kit Order Code: K8048 - **£23.94***
*Assembled Order Code: VM111 - **£39.12***

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £11.52

USB Experiment Interface Board

5 digital input channels and 8 digital output channels plus two analogue inputs and two analogue outputs with 8 bit resolution.
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*Kit Order Code: 8157KT - **£49.95***
*Assembled Order Code: AS8157 - **£54.95***

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
*Kit Order Code: 3145KT - **£19.95***
*Assembled Order Code: AS3145 - **£26.95***
*Additional DS1820 Sensors - **£4.95 each***

Remote Control Via GSM Mobile Phone

Place next to a mobile phone (not included). Allows toggle or auto-timer control of 3A mains rated output relay from any location

Most items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix).

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, **Rings** to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
*Kit Order Code: 3140KT - **£79.95***
*Assembled Order Code: AS3140 - **£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

Infrared RC 12–Channel Relay Board

Control 12 onboard relays with included infrared remote control unit. Toggle or momentary. 15m+ range. 112 x 122mm. Supply: 12Vdc/0.5A
*Kit Order Code: 3142KT - **£64.95***
*Assembled Order Code: AS3142 - **£74.95***

Audio DTMF Decoder and Display

Detect DTMF tones from tape recorders, receivers, two-way radios, etc using the built-in mic *or* direct from the phone line. Characters are displayed on a 16 character display as they are received and up to 32 numbers can be displayed by scrolling the display. All data written to the LCD is also sent to a serial output for connection to a computer. Supply: 9-12V DC (Order Code PSU375). Main PCB: 55x95mm.
*Kit Order Code: 3153KT - **£37.95***
*Assembled Order Code: AS3153 - **£49.95***

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Kit Order Code: 8191KT - £29.95
Assembled Order Code: AS8191 - £39.95

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

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4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application.
*Kit Order Code: 3190KT - **£84.95***
*Assembled Order Code: AS3190 - **£99.95***

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Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
*Kit Order Code: 3187KT - **£39.95***
*Assembled Order Code: AS3187 - **£49.95***

Video Signal Cleaner

Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
*Kit Order Code: K8036 - **£24.70***
*Assembled Order Code: VM106 - **£36.53***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
*Kit Order Code: 3067KT - **£19.95***
*Assembled Order Code: AS3067 - **£27.95***

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
*Kit Order Code: 3166v2KT - **£23.95***
*Assembled Order Code: AS3166v2 - **£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
*Kit Order Code: 3179KT - **£17.95***
*Assembled Order Code: AS3179 - **£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver

Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
*Kit Order Code: 3158KT - **£24.95***
*Assembled Order Code: AS3158 - **£34.95***

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
*Kit Order Code: 1074KT - **£15.95***
*Assembled Order Code: AS1074 - **£23.95***

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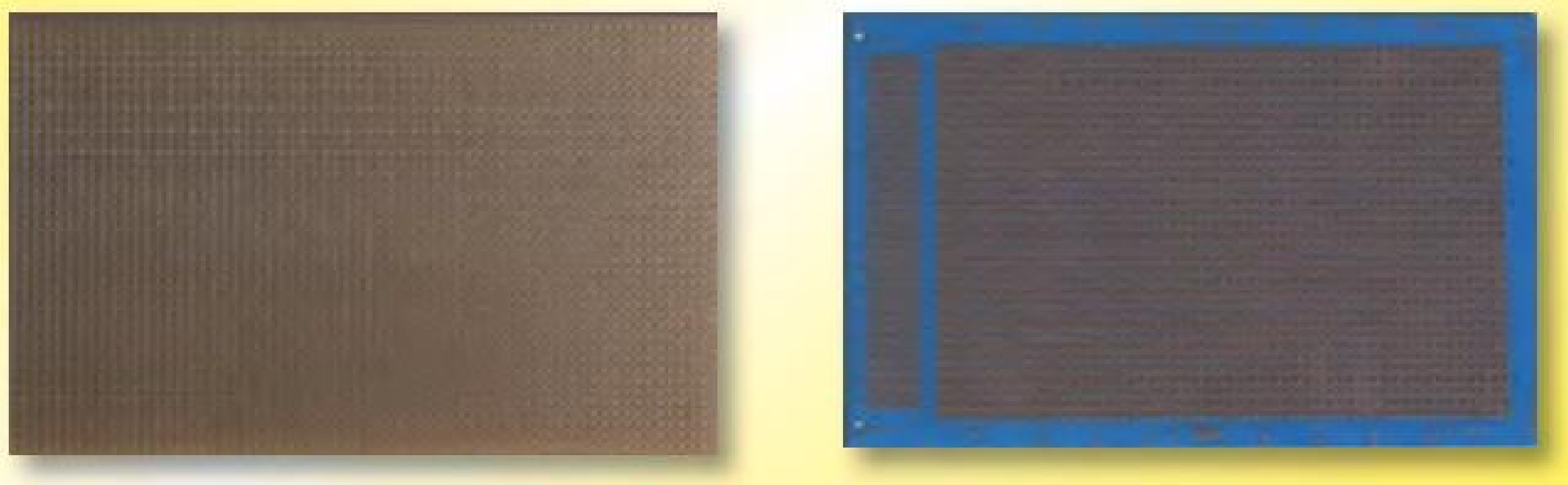

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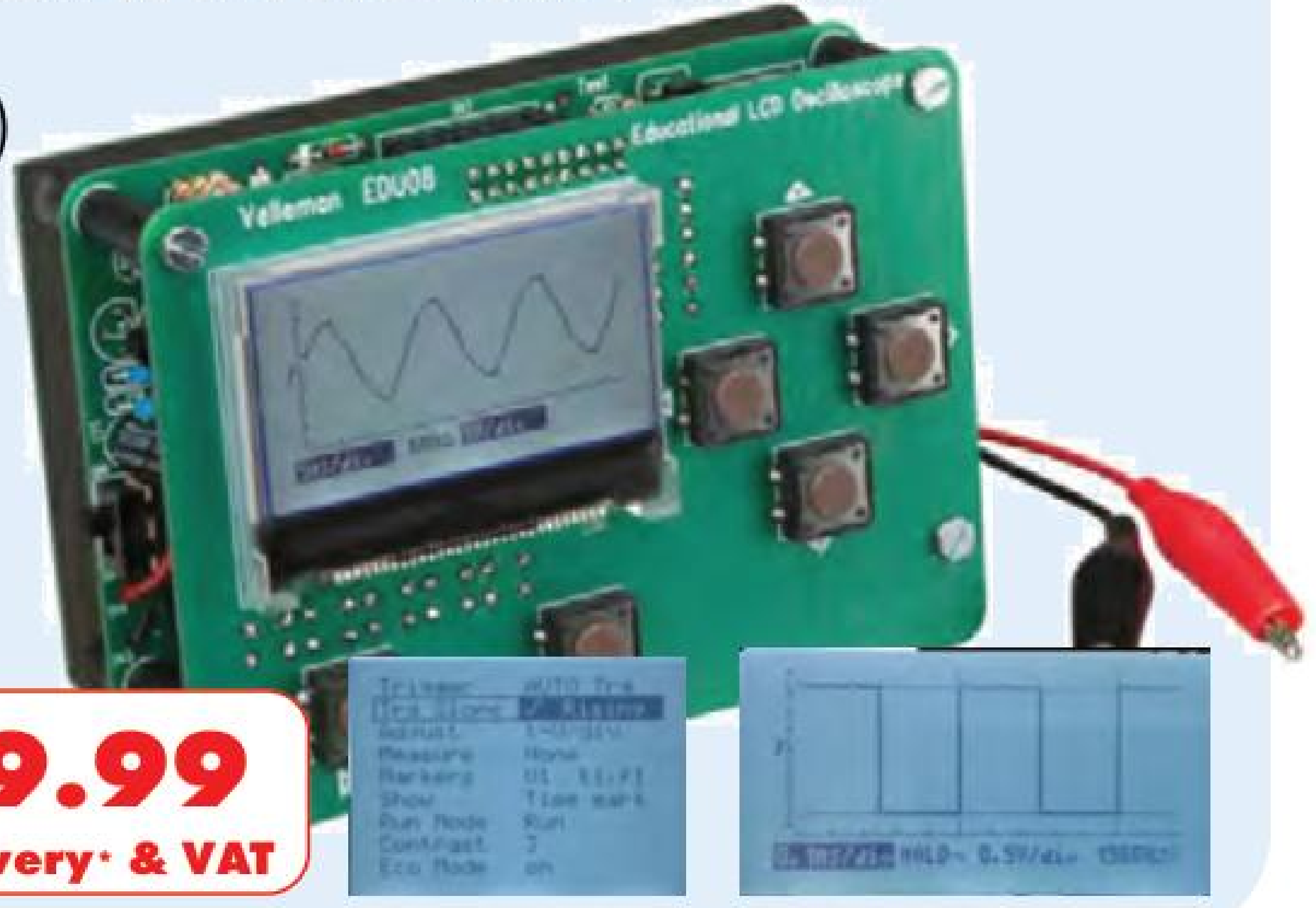

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EVERYDAY PRACTICAL ELECTRONICS

Happy New Year!

This may be the March issue, but I'm writing on New Year's Day, so it seems a good opportunity to wish all our readers the very best for 2016.

In the December issue I gave a very brief run down of some of the electronic delights awaiting you in 2016 – top of the list for me has to be the current Arduino *Teach-In* series from Mike and Richard Tooley. It is true that the Ardunio lacks the 'fire power' of a high-end microcontroller like the latest PIC devices, but often such devices are overkill. If you just need to add some 'smarts' to a project to monitor slow-moving data, or run a display then the Arduino is the prefect choice to get you up and running quickly.

So much for *EPE*, but what about the rest of the tech world? Well, although I agree with Nils Bohr, the Danish Nobel laureate in Physics, who wisely noted, 'prediction is very difficult, especially if it's about the future', here are two trends that I will be watching closely – electric vehicles and smart watches.

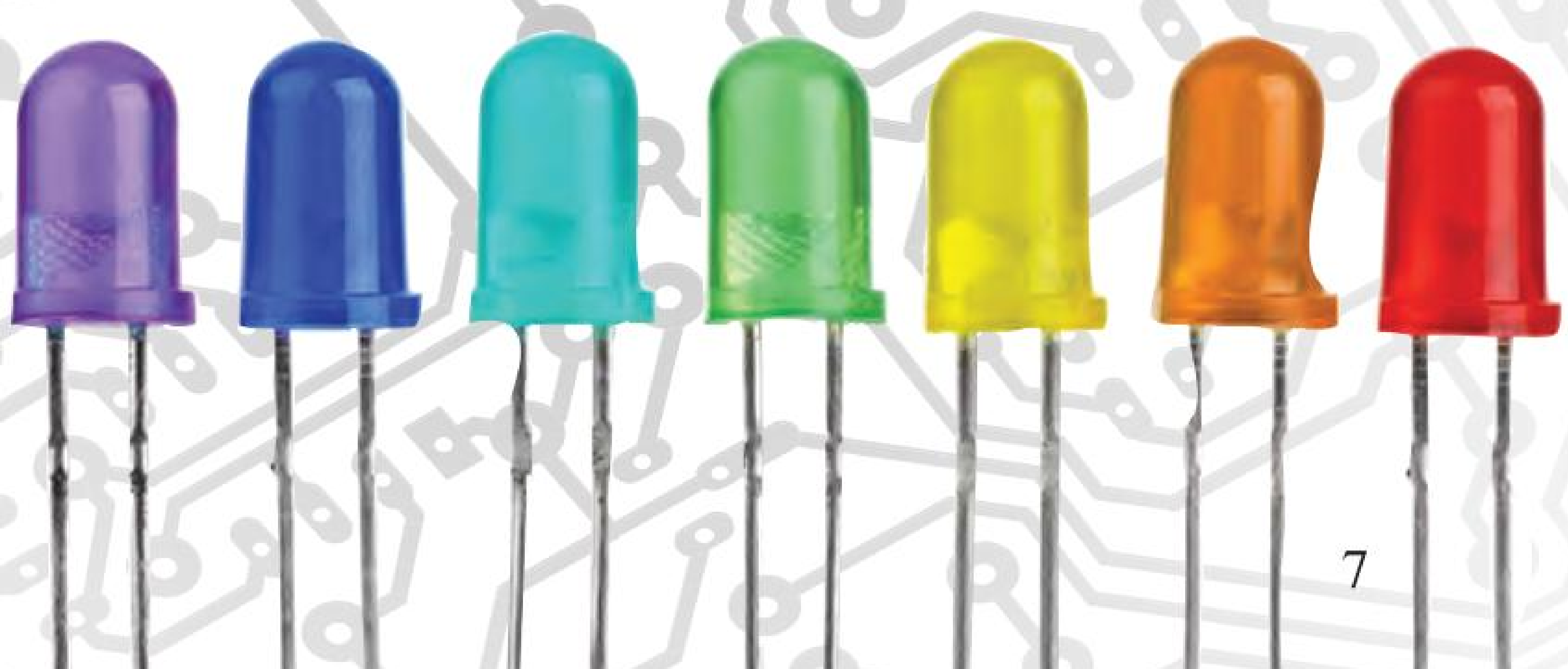
The car's the star

Last year, the world's automotive industry produced over 90 million vehicles, generating £6 trillion of revenue. In the US alone, half a trillion litres of petrol were used. However, despite the internal combustion engine's immense popularity and the current low price of oil, the incentives and pressure to go electric will only increase. We may be clever at finding new ways to extract oil, but sooner or later it will run out, and of course the elephant in the room is pollution and climate change. We know how to make low-impact electricity, an enormous distribution network already exists and the outlook for batteries gets better every year. Could this be the year electric cars take off? I honestly don't know, but I do know that more and more high-volume manufacturers are taking electric vehicles very seriously indeed. 'EVs' are definitely on the horizon, perhaps 2016 will bring the charging and storage solution that is the crucial game changer.

Smart watch or health monitor?

I like my Apple Watch; it has some nice apps, but I would never pretend it has had the same effect on my working and social life as an iPhone. However, I am sure Apple has big plans for their little wearable. Top of the list for me will be comprehensive health monitoring. If you think the automotive industry is big, then look at the health sector. 17% of US GDP is spent on health, and even in austerity Britain it is 9%. My guess is that Apple will add more health-monitoring sensors to their watch in its next iteration and in the longer term you will be able to get your GP to insert a blood monitor the size of a grain of rice just under your skin that will talk to the watch. The effect on diabetes management alone could be staggering.

With all due respect to Nils Bohr, those are my ideas – what about yours?



NEWS

A roundup of the latest Everyday News from the world of electronics

Broadcasters face online challenges – *report by Barry Fox*

Online TV viewing is fast becoming a way of life. Even the BBC, despite its name – the British Broadcasting Corporation – is taking BBC3 off-air and putting it online. Ahead of Christmas, UK regulator Ofcom was predicting that 70% (31 million) of UK adults would watch TV using free-to-air catch-up services such as BBC iPlayer and ITV Hub in December, putting the UK ahead of all other major European countries the US, Japan and Australia.

Whether the Internet can support the ever-increasing traffic load remains to be seen. And the downside of buying hardware with built-in online viewing options is now starting to emerge.

Some broadcast content is deliberately free, but how will the TV and cable industry tackle online piracy?

Amazon Prime and PS3

The Amazon Prime app, which came with Samsung 'smart' TVs, has now been disabled on some models, and owners have been advised to buy a bolt-on hardware solution if they want to continue watching. Amazon took the shutdown as an opportunity to offer special deals on its range of Fire TV devices.

Owners of Sony PS3 consoles can no longer use the built-in ITV catch-up service. Says a spokesman for ITV, cheerily: 'We've now closed ITV Player on Playstation 3, so we can focus on developing the ITV Hub for a wide variety of platforms. Don't worry; you can still catch up on all your favourite shows via desktop, our mobile and tablet apps, and a variety of Smart TV's. Sorry for the disappointment'.

Online piracy

Although the content providers do benefit financially from putting programmes online, rather than producing discs that have to be pressed, packaged, stored and shipped – and which pirates can copy – they now face a new threat, online piracy. According to computer security specialists McAfee Labs (now owned by Intel), hackers are now selling stolen subscriptions to online video services including Netflix and HBO.

HDMI loophole

The use of bolt-on online boxes, connected to a TV by HDMI cable, creates a gaping security gap. Although the HDMI connection is copy-protected by Intel's HDCP (High-bandwidth Digital Content Protection) it's easy to buy black boxes that convert a digital HDMI stream to analogue High Definition Component video, which is unprotected and easily captured like console gameplay as digital video with a PC.

Ironically, Amazon sells devices that can copy its own Prime content!

Can the industry tackle the problem?

The European Content Protection Summit, held recently in London, showed a sobering lack of technical understanding on these issues.

A panel session on 'How Secure are Secure Distribution Platforms?' gathered some heavyweight experts: André Roy, Head of Security Practice at Farncombe; Richard Atkinson, ex-Disney and Global Director on Piracy at Adobe, and Chairman of the industry Content Delivery & Security Association (CDSA); Robin Boldon, Director of Digital Distribution, BBC Worldwide; and David Whittaker, Director of Business Development at Cisco.

I asked the panel what had happened to Cinavia, the clever system which buries inaudible codes in the sound of any content. The codes then trigger the shutdown of any playback device that is Cinavia-enabled. All Blu-ray players (and consoles) are enabled and the system works very efficiently.

The Panel passed the question to Richard Atkinson, who started talking dismissively about 'a non-standard disc and player'. Someone in the audience reminded him that he was talking about a completely different system called Cinea, which was briefly used to protect content given to Academy Award judges.

Finally, remembering what Cinavia was, Atkinson then said the 'industry had not been able to unify' because there had been 'challenges over licensing and cost to the companies', and 'unless it's an industry standard and everybody does it and Microsoft doesn't want to put it in Windows' because 'if discs don't play, people blame Microsoft'.

'It was difficult to get all players to the table and it's difficult to create an industry standard', Atkinson continued. 'Disney did incorporate it for a while but the industry didn't rally round and these things fall by the wayside'.

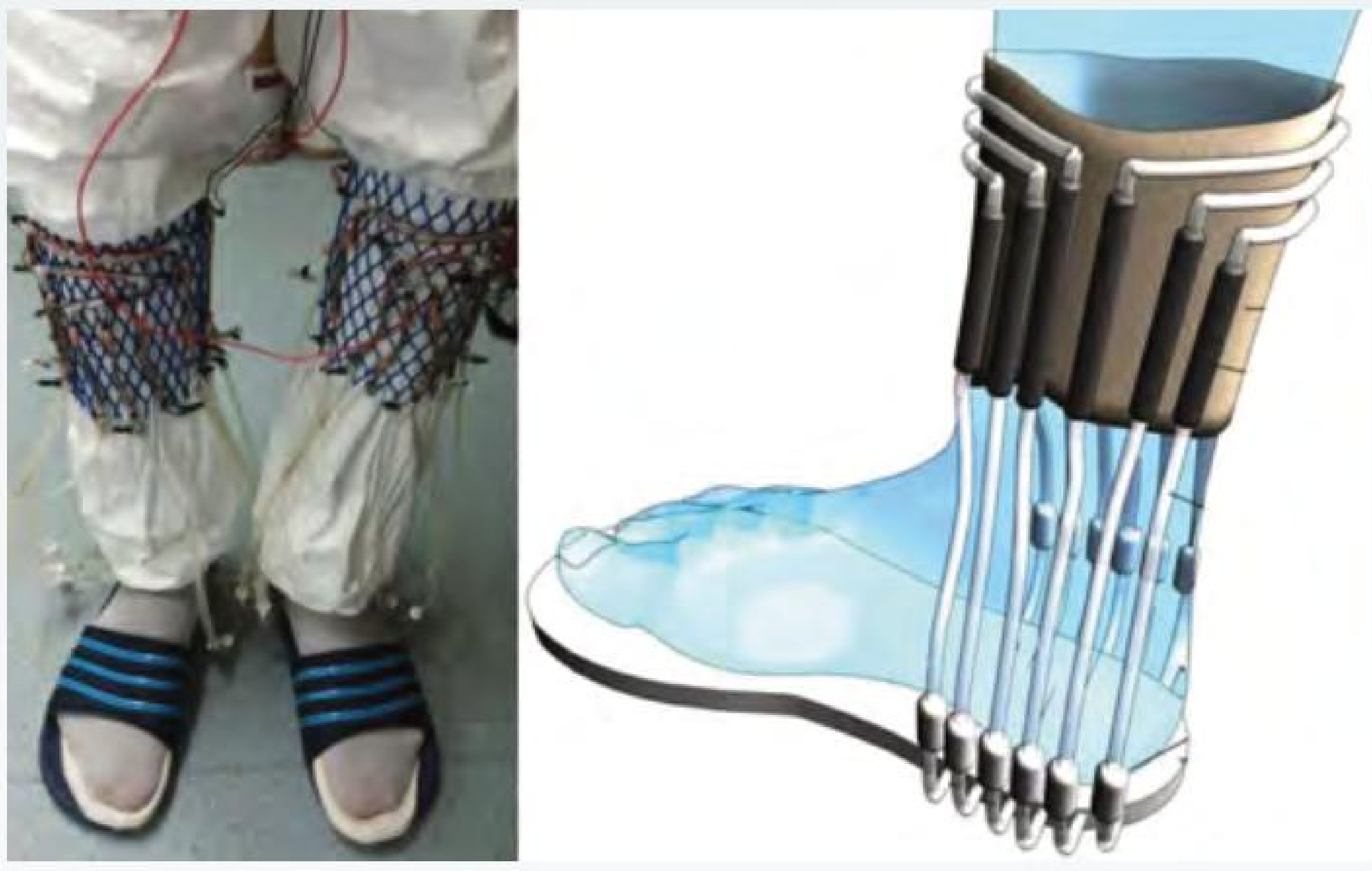
Not just a pretty face

Thanks to quartz crystals we are so used to electronic watches being accurate that it is easy to miss one of the key features of the Apple Watch – its precise timekeeping. Apple claims it keeps within 50ms of the global time standard and is so accurate that the hands of two Apple Watches placed next to one another will move in perfect unison. This is achieved primarily through 15 Network Time Protocol (NTP) servers that Apple has around the world, with GPS antennas that connect to GPS satellites broadcasting time data from the US Naval Observatory in Washington DC. (The Observatory houses an atomic clock.)

Apple's time servers communicate the time to iPhones across the world, and the iPhone in turn syncs with the Apple Watch via Bluetooth to provide the exact time. Communicating a GPS signal from a server to an iPhone to an Apple Watch over Bluetooth has its own delays, which Apple corrects for via software. Apple's NTP servers make sure iPhones and Apple Watches keep time at 'Stratum One' accuracy, within milliseconds of 'Stratum Zero' devices.

On top of this, every Apple Watch has a temperature-controlled crystal oscillator to offset time drift. The oscillator also makes sure the Apple Watch remains warm enough to keep accurate time in very cold climates. Thanks to this hardware, the Apple Watch is even more accurate than the iPhone.

The power of pee



Essential footware for when you need just a little juice to power some wearable or portable electronics

Fancy running your Wii on wee? Well, that maybe a few watts too much at the moment, but the principle has been developed at the University of the West of England (UWE) in Bristol. They have built a wearable energy generator that uses urine to power a wireless transmitter.

A pair of socks embedded with miniaturised microbial fuel cells (MFCs) and fuelled with urine pumped by the wearer's footsteps has powered a wireless transmitter to send a signal to a PC. This is the first self-sufficient system powered by a wearable energy generator based on microbial fuel cell technology.

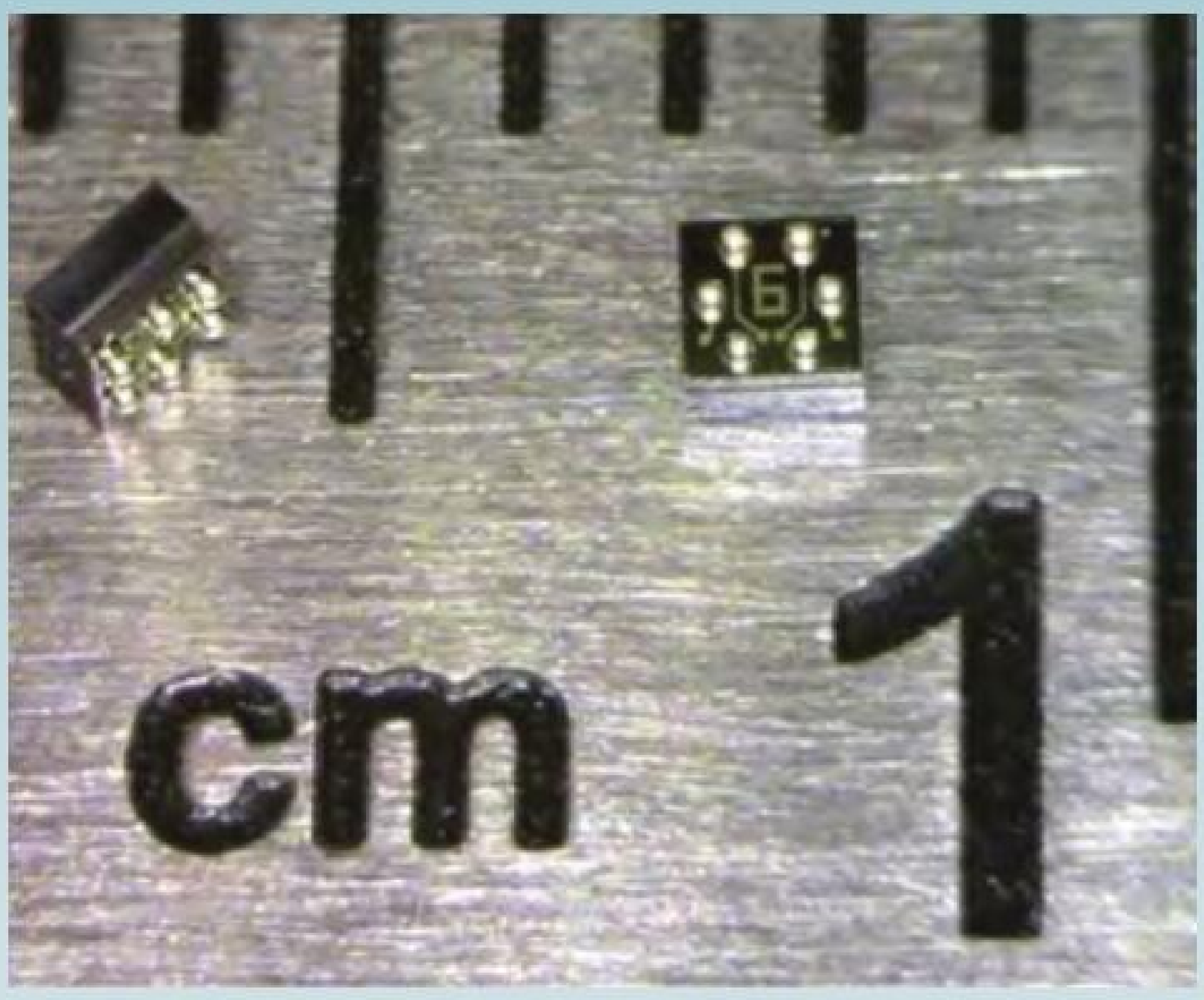
Normally, continuous-flow MFCs would rely on a mains-powered pump to circulate the urine over the microbial fuel cells, but this experiment relied solely on human activity. The manual pump was based on a simple fish circulatory system and the action of walking caused the urine to pass over the MFCs and generate energy. Soft tubes, placed under the heels, ensured frequent fluid push-pull by walking. The wearable MFC system successfully ran a wireless transmission board, which was able to send a message every two minutes to the PC-controlled receiver module.

Designer Dr Ieropoulos says, 'Having already powered a mobile phone with MFCs using urine as fuel, we wanted to see if we could replicate this success in wearable technology. We also wanted the system to be entirely self-sufficient, running only on human power – using urine as fuel and the action of the foot as the pump.'

MFCs use bacteria to generate electricity from waste fluids. They tap into the biochemical energy used for microbial growth and convert it directly into electricity. This technology can use any form of organic waste and turn it into useful energy without relying on fossil fuels, making this a valuable green technology.

The Centre has recently launched a prototype urinal in partnership with Oxfam that uses pee-power technology to light cubicles in refugee camps.

Tiny 3-axis accelerometer



US company mCube has shrunk the size of its tri-axis accelerometer to 1.1mm by 1.1mm by 0.74mm in height – smaller than a grain of sand.

The device is built upon the company's 3D monolithic single-chip MEMS technology platform which combines MEMS and CMOS using through-silicon vias (TSVs) to minimise or eliminate the use of wirebonds. 8, 10, or 14-bit resolution options are available, with output data rates up to 1024Hz and selectable interrupt modes via an I^2C bus.

New Picoscope software launched

PC oscilloscope manufacturer Pico Technology has introduced Release 6.11.7 of its PicoScope software.

'The new version addresses many challenges with the addition of mathematical waveform processing tools, decoding of popular serial protocols, and improvements to FFT frequency domain plotting. For users with touchscreens, Pico has introduced pinch and zoom support to enable easy panning and positioning of captured waveforms', said Trevor Smith, Business Development Manager for Test & Measurement products at Pico.

Advanced waveform mathematics now includes user-configurable filters: high pass, low pass, band pass and band stop.

Frequency and duty cycle versus time plotting is a new feature. With those plots it is possible to measure clock jitter and wander, modulation depth and characteristics of FM signals on a cycle-by-cycle basis.

PicoScope has support for a total of sixteen bus protocols, including SENT, 10- and 100BASE-T Ethernet, DMX512 (lighting systems) and DCC (model railways). Support for older standards such as I^2C, SPI, CAN and UART / RS-232 has been updated and improved.

Download the latest version from: **www.picotech.com/downloads**

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TechnoTalk

The mysterious mag amp

Mark Nelson

Genuine experts will know that there's nothing mysterious about mag amps, but even they will concede that most people have never heard of theses devices. If you're one of the latter, suspend your scepticism for a moment and read on, as Mark Nelson peels away the layers of obscurity.

LET'S GO BACK TO ABSOLUTE basics this month, the kind of fundamentals you were taught back in the last century when you took your first faltering steps in the new world of electronics. One of the first concepts you learnt was the amplification of voltages and currents, and power and decibels. Your teacher almost certainly explained that electronic amplifiers came in two sorts, hollow state, using thermionic devices (valves or tubes), and solid-state, employing transistors and integrated circuits. My apologies if this all sounds a bit too basic, but I have to set the scene first and I imagine that your mentor never mentioned there was any other kind of amplifier.

The third way

But just as in politics, there is in fact a third way, known as the 'magnetic amplifier' ('mag amp' for short). Actually, there is also a fourth way, but we'll come to that at the end of this article.

In some circles, the magnetic amplifier holds a position of near-mystical status and is considered by some as a 'lost technology' on a par with Nikola Tesla's scheme for distributing electrical power through the ether or his frightening directed energy weapon (**https://en.wikipedia.org/wiki/Nikola_Tesla**). Though discovered about 100 years ago and appearing in the literature by name as early as 1916, the magnetic amplifier has been long forgotten by electronicists. The advent of first the vacuum tube and then the transistor, each with faster response and apparently more efficient operation, completely overshadowed the use of saturable devices (and there, I have just dropped in a clue as to how the magnetic amplifier operates). So, how does it work and what can it do?

Weird and wonderful

Even though I'd not heard of mag amps until two days ago, Wikipedia knew about it all along (**https://en.wikipedia.org/wiki/Magnetic_amplifier**). Summarising what is said – although a mag amp device *looks* like a transformer, its operating principle is entirely different. The mag amp is in effect a 'saturable reactor', a device that has been supplanted by thyristor controls using triacs or silicon controller rectifiers (SCRs).

Your typical magnetic amplifier will consist of two physically separate transformer magnetic cores, each having two windings: a control winding and a power winding. The amount of control current fed into the control winding sets the point in the power winding's AC waveform at which either core will saturate. In saturation, the AC winding on the saturated core will go from a high-impedance state (let's call this 'off') into a very low-impedance state ('on'). In other words, the control current determines at which voltage the mag amp switches 'on'. Consequently a relatively small DC current in the 'control' winding can control or switch large AC currents in the AC 'power' windings. This results in current amplification.

Cons and pros

So what's not to like? In a mag amp the gain available from a single stage is limited and low compared to electronic amplifiers. The frequency response of a high-gain amplifier is limited to about one-tenth of the excitation frequency. Solid-state electronic amplifiers can be more compact and efficient than magnetic amplifiers.

On the plus side, the magnetic amplifier is extremely robust, with no moving parts, no wear-out mechanism, no warm-up time and good tolerance to mechanical shock and vibration. The coils have a higher tolerance to momentary overloads than comparable solid-state devices, while the cores can withstand neutron radiation extremely well, making them suited to applications in nuclear electronics (nucleonics).

Mag amps have found many uses over the years, not all of them in the dim and distant past. During the very early days of speech radio, mag amps were employed as the modulation and control amplifier. They were also used in the stabiliser controls of the V2 rocket terror weapons of World War Two. In more recent times, the *Concorde* airliner made use of this technology for controlling engine air intakes before development of a system using digital electronics. Mag amps were used extensively in early switched-mode power supplies, and ATX-type power supplies in PCs often use mag amps for secondary side voltage regulation.

To write off the mag amp as an irrelevant side alley of electronic development would be wrong in my opinion, and the technology was held in high regard in the days before high-power solid-state devices were available. You can read a fulsome US government report on mag amps at: **http://teslapress.com/magamp.pdf** and another that argued 'the magnetic amplifier is returning as a real competitor to the vacuum tube' at: **http://tinyurl.com/hl4zqd2**

The fourth way

Yes dear reader, there is indeed a fourth way, although you'll probably accuse me of stretching the facts when I describe it. That's because we're talking about mechanical amplifiers, which although used (mainly) in systems that we would now classify as electronic, did not employ any electronic mechanism. Mechanical amplifiers do deserve a mention, so here we go.

In the early days of public address systems, before thermionic valves were sufficiently powerful or robust, several firms devised systems that operated mechanically using compressed air and a vast 'fog horn', all driven by an electric compressor (**www.douglas-self.com/MUSEUM/COMMS/auxetophone/auxetoph.htm**). One was used on the London Underground to tell passengers to 'Keep moving!'; see the photo at: **http://tinyurl.com/z2ytsda**. These devices must be seen to be believed!

Another kind of mechanical amplifier was used in telephone circuits; this was effectively a sensitive earpiece placed in front of a sensitive microphone, all enclosed in a soundproof wooden box. These amplifiers worked reasonably well and items of this kind, made by SG Brown, were used by the British army in World War One. They turn up on eBay quite regularly and fetch fairly elevated high prices (£110 in July 2015, item 252003029569). There's one to be seen in a virtual museum at: **www.douglas-self.com/MUSEUM/COMMS/mechamp/mechamp.htm**

6-Digit Retro Nixie Clock

. . . now with optional GPS time

This *6-digit Nixie Clock* includes features such as GPS-locked time, date display, 7-day alarm, auto-dimming, 12/24 hour time and optional leading-zero blanking. Having described the circuit and software operation in Part 1 last month, this time we describe how to put the kit together.

Part 2: By Nicholas Vinen

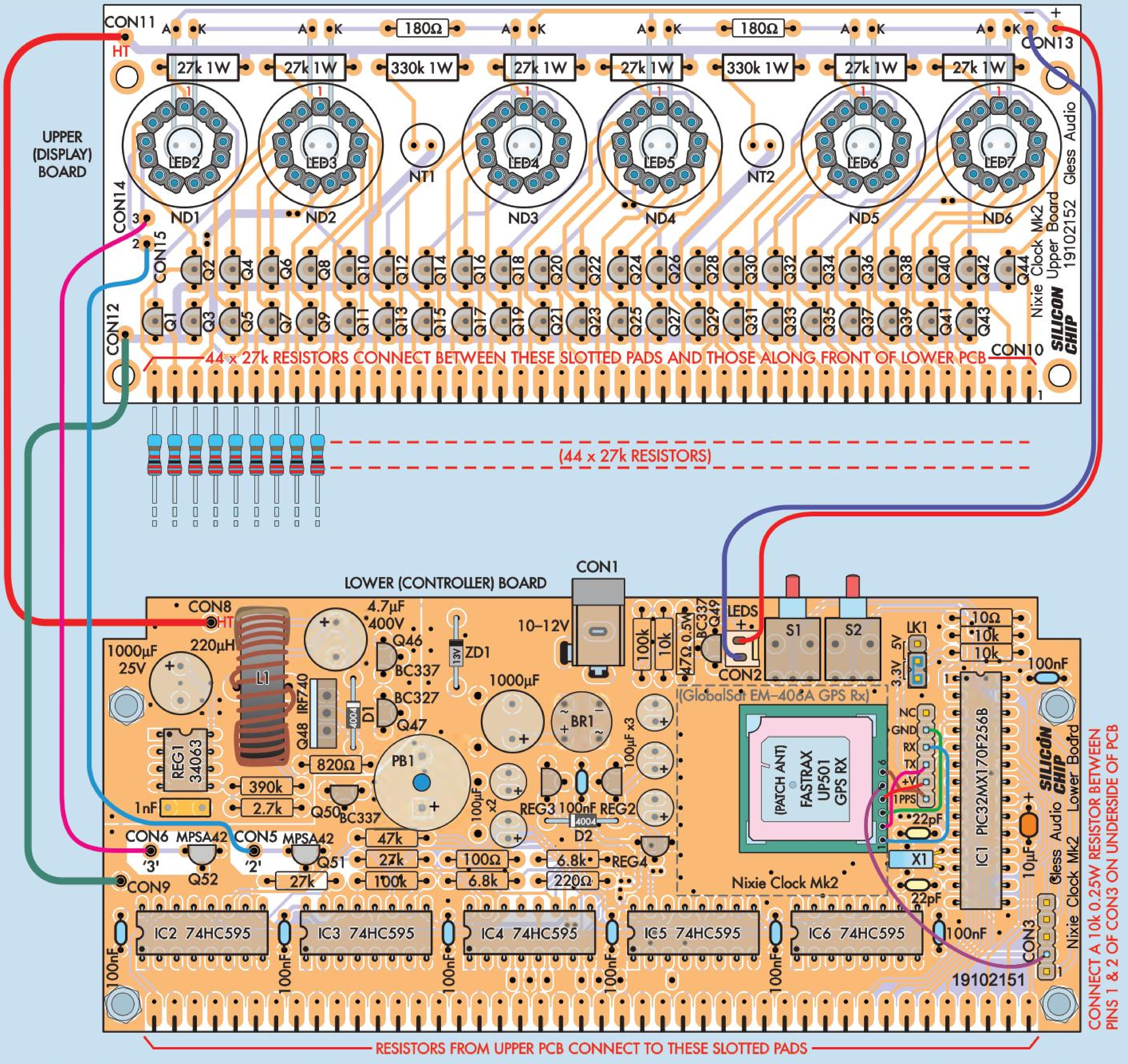

UPPER (DISPLAY) BOARD
CON11
HT
A K
180Ω
27k 1W
330k 1W
CON13
LED2
LED3
LED4
LED5
LED6
LED7
NT1
NT2
ND1
ND2
ND3
ND4
ND5
ND6
CON14
CON15
CON12
CON10
Nixie Clock Mk2 Upper Board 19102152 Gless Audio
SILICON CHIP
44 x 27k RESISTORS CONNECT BETWEEN THESE SLOTTED PADS AND THOSE ALONG FRONT OF LOWER PCB
(44 x 27k RESISTORS)
LOWER (CONTROLLER) BOARD
CON1
10–12V
CON8
HT
4.7µF 400V
220µH
1000µF 25V
L1
Q46 BC337
Q47 BC327
Q48 IRF740
ZD1
D1 4004
1000µF
BR1
REG1 34063
PB1
390k
2.7k
820Ω
1nF
Q50 BC337
REG3
REG2
100nF
D2
REG4
100µF x2
100µF x3
100k
10k
47Ω 0.5W
BC337 Q49
LEDS
CON2
S1
S2
LK1
3.3V 5V
10Ω
10k
10k
100nF
(GlobalSat EM-406A GPS Rx)
[PATCH ANT] FASTRAX UP501 GPS RX
NC
GND
RX
TX
+V
1PPS
22pF
X1
22pF
IC1 PIC32MX170F256B
10µF
Gless Audio Nixie Clock Mk2 Lower Board
19102151
CON3
CON6
MPSA42
Q52
'3'
CON5
MPSA42
Q51
'2'
CON9
47k
27k
100k
27k
100Ω
6.8k
6.8k
220Ω
IC2 74HC595
IC3 74HC595
IC4 74HC595
IC5 74HC595
IC6 74HC595
100nF
Nixie Clock Mk2
RESISTORS FROM UPPER PCB CONNECT TO THESE SLOTTED PADS
CONNECT A 10k 0.25W RESISTOR BETWEEN PINS 1 & 2 OF CON3 ON UNDERSIDE OF PCB

Fig.3: follow this PCB layout and wiring diagram to build the *Nixie Clock.* The sockets on the upper board are made from snapped sections of socket strip – note how they are arranged. The GPS module connections shown are for the Fastrax UP501; other modules will require different connections so refer to Fig.5 or the appropriate data sheet and observe the connector pin labelling. Once the two boards are joined by four spacers, the six wires between them can be connected and the 44 × 27kΩ resistors soldered into the slots along the front. Don't forget to add the 10kΩ 0.25W resistor between pins 1 and 2 of CON3 on the underside of the PCB.

THE NIXIE CLOCK COMES exclusively as a kit from Gless Audio and there are various options, eg, whether or not the case is included. Regardless of which kit you choose, you will need to begin by building the two boards and joining them together.

Start by checking the slots along the front of the two double-sided boards. Due to the way the slots are made, some may be partially blocked with copper fragments. If so, use a small piece of stiff wire to clear them out.

Now fit the small (0.25W and 0.5W) resistors on both boards. Use parts layout diagram Fig.3 to guide you. It's a good idea to measure the resistors with a DMM before fitting them because resistor colour code bands can be hard to read.

You will be left with a number of 27kΩ resistors. While two of these are fitted to the lower board, the rest will later be soldered between the two boards, so set them aside for now.

Finishing the upper PCB

Note that the upper board shown in Fig.3 has been changed slightly from the original and it's possible you could get an earlier revision in the kit (the same one used in our photos). You can ignore the differences as they don't affect operation in the slightest.

Proceed to solder the eight 1W resistors in place on the upper board, as shown in Fig.3. Then, carefully snap the two 40-pin socket strips into 36 sections with two pins and then snap six single pins off the remaining strips. These form the Nixie tube sockets, arranged as shown in Fig.3.

Check after soldering that each section is sitting right down on the PCB.

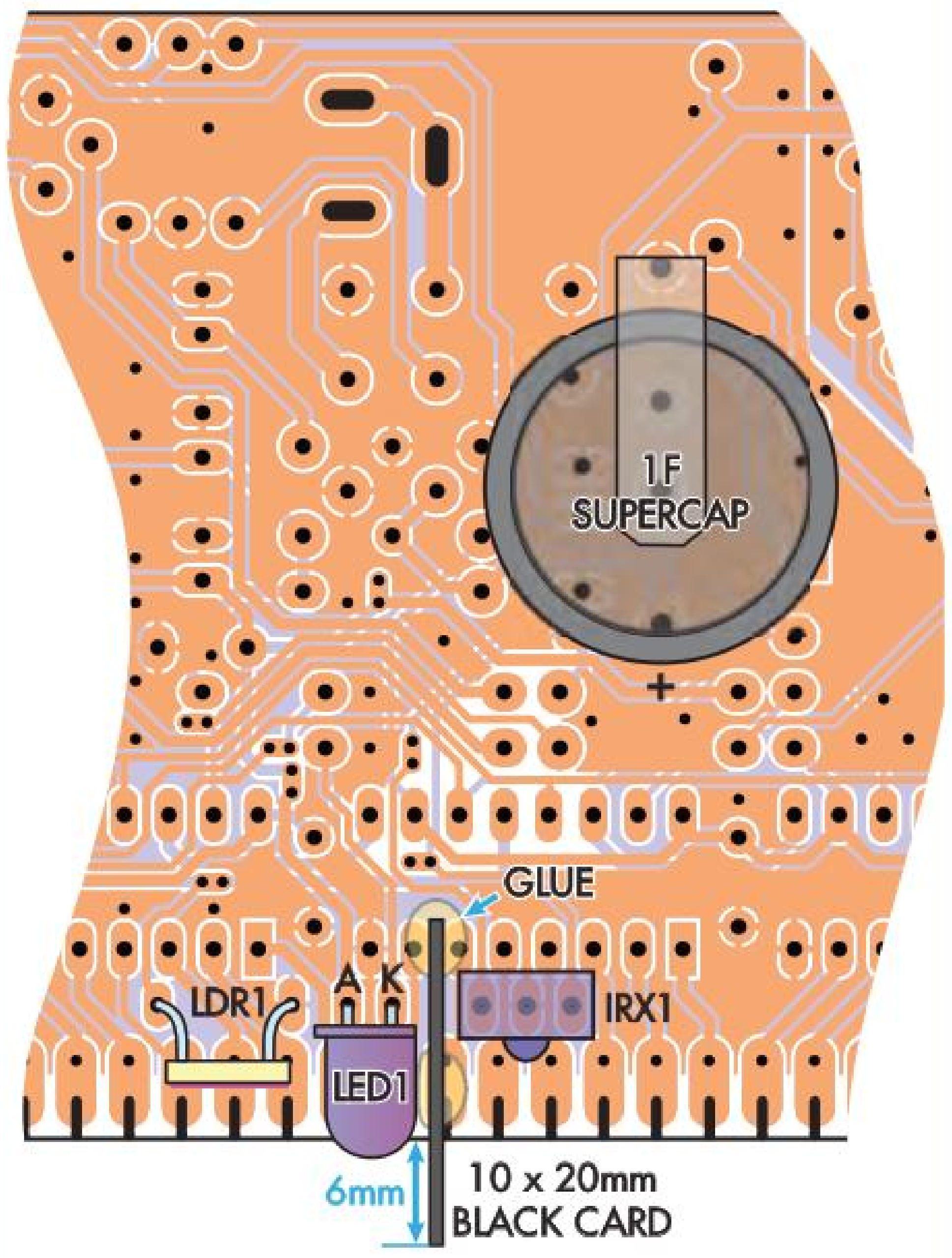
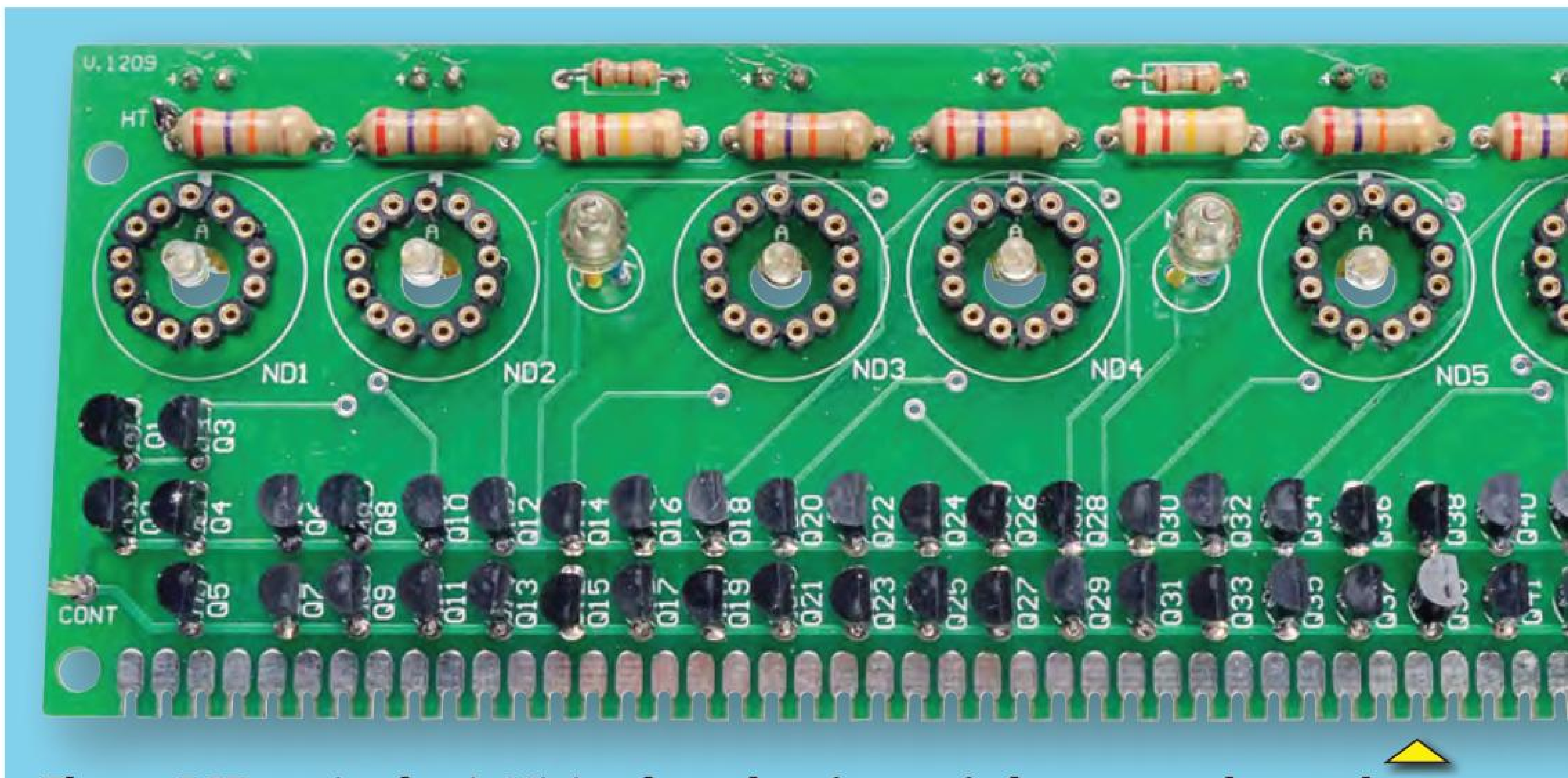


Fig.4: four components are soldered to the underside of the lower PCB, as shown here. Note that two different sets of pads are provided for the supercap to suit different brands. The capacitor supplied with the kit is likely to use the outer pair. The small piece of black card is glued into place once all four of the parts shown have been fitted.



The top PCB carries the six Nixie tube sockets (see text), the two neon lamps, the 44 segment-driver transistors and the six blue LEDs which illuminate the bases of the Nixie tubes. Check that all parts are correctly seated and oriented before soldering their leads and note that the six LEDs are mounted on the bottom of the PCB (see photo on facing page).

The 44 high-voltage transistors can be installed next. These are all the same type. MPSA42 types will probably be supplied but MPSA44 and 2N6517 are valid alternatives. Note that there are several other similar-looking devices in the kit, so put those aside first.

Fit all 44 transistors on the upper board with the same orientation, ie, flat side to the right, as shown in Fig.3. You will need to crank the leads out using small pliers to suit the pad spacings on the PCB. Make sure that they are all pushed down fully before soldering – if they aren't, when you go to fit the perspex cover later, you will find that it can't be screwed down properly.

Next come the six blue LEDs. These poke up through a hole in the middle of each socket but are actually fitted on the underside of the board and soldered to pads near the top edge.

Start by bending one of the LED's leads down by 90° about 3mm from its body, at the same time ensuring that its polaity will be correct when it is mounted in position (see Fig.3). That done, cut a couple of lengths of small diameter heatshrink tubing and slip them over the leads so that they are insulated all the way from the LED's lens until just before they reach its two solder pads. It's then just a matter of bending the ends of the leads up to pass through these pads before shrinking the tubing down and soldering the leads in place.

Repeat this procedure for the other five LEDs, checking the orientation in each case. The photo on the facing page shows the details.

Finally, fit the two neon lamps. These are installed with the bottom of the glass envelopes 10mm above the top of the PCB and with the exposed leads covered with heatshrink tubing.

Parts list additions

In the parts list last month, we left out the 28-pin DIL socket for the microcontroller (IC1). Also, the case is held together with 16 self-tapping screws rather than the 12 specified and it also includes four stick-on feet.

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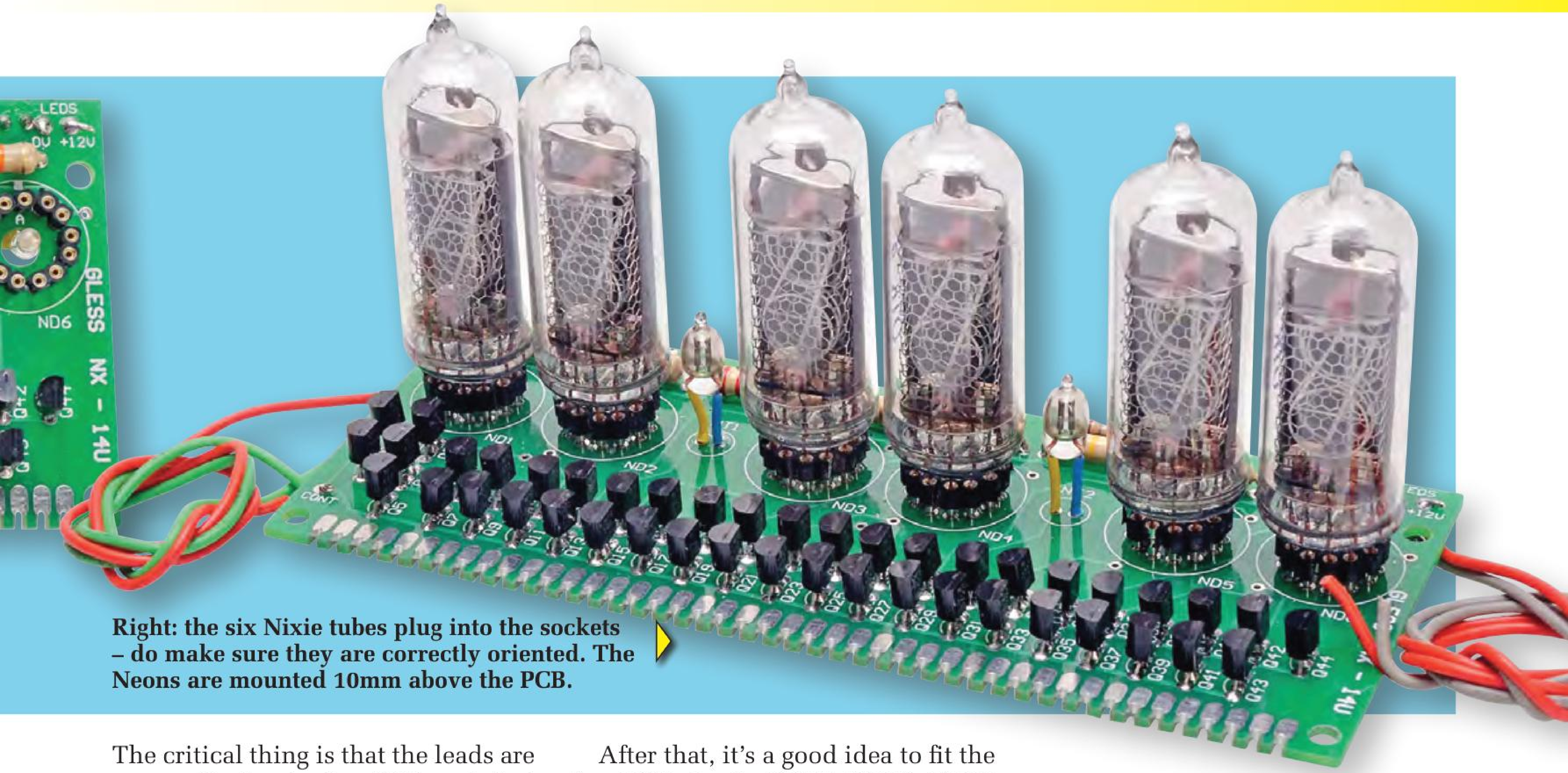


Right: the six Nixie tubes plug into the sockets – do make sure they are correctly oriented. The Neons are mounted 10mm above the PCB.

The critical thing is that the leads are perpendicular to the PCB and that the two lamps are at the same height. These form the hour/minute and minute/second separators.

If you cut the heatshrink sections all to the same length (around 11mm) prior to shrinking and keep them butted up against the underside of the lamps, these will then form natural spacers to allow you to get a consistent stand-off height between the two.

Assembling the lower PCB

Continue the lower PCB assembly by installing diodes D1 and D2 and zener diode ZD1. Check Fig.3 to see which goes where as there are three different types. Make sure that they are oriented as shown.

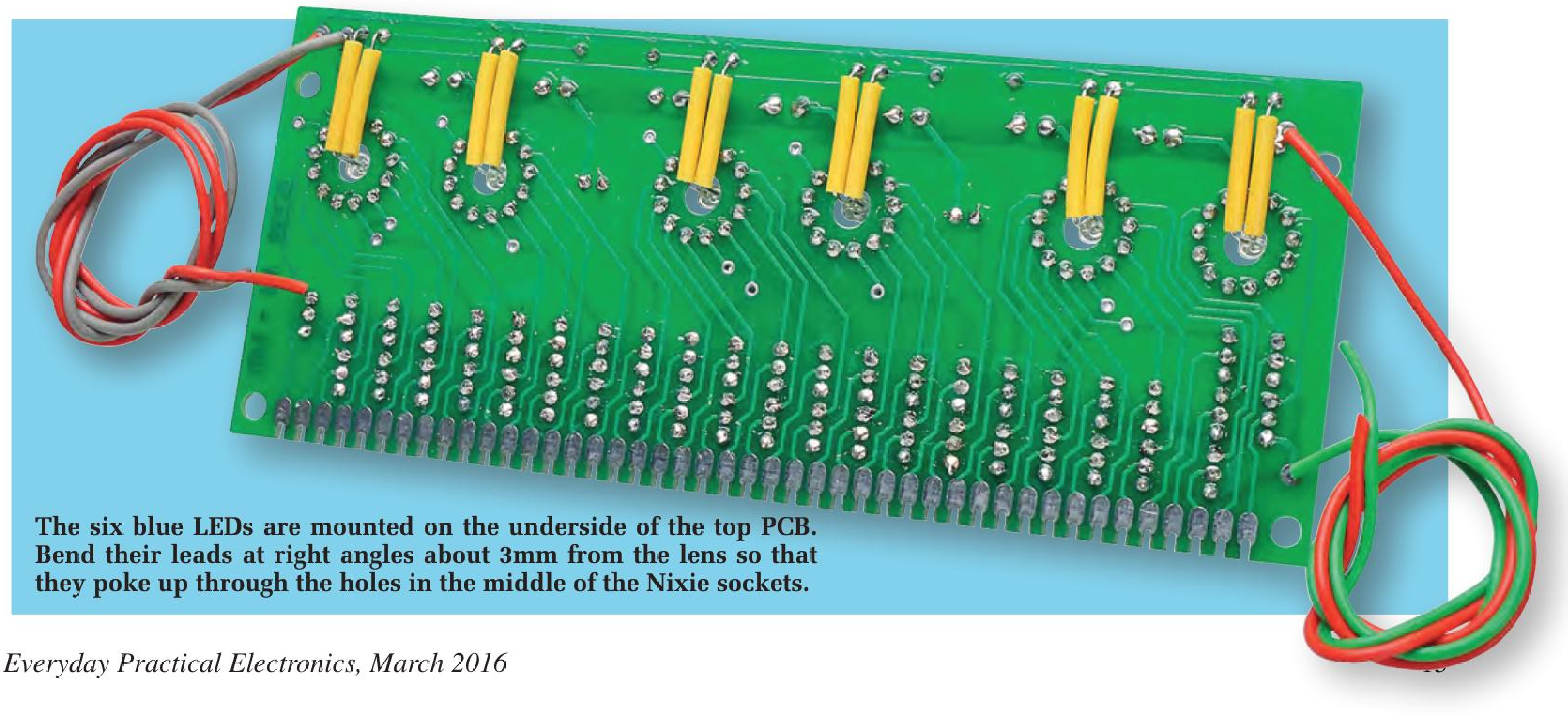
After that, it's a good idea to fit the four PCB pins for CON5, CON6, CON8 and CON9. This is because they are a tight fit and you will probably need to hammer them in before soldering. The tightness is so they don't fall out when you flip the board over to solder them.

Now mount the IC socket for microcontroller IC1, then install IC2-IC6 and REG1 which do not require sockets. Having said that, you may be supplied with sockets for IC2-IC6, in which case you can use them; it does eliminate the possibility of accidentally soldering an IC in backwards which can be very difficult to fix!

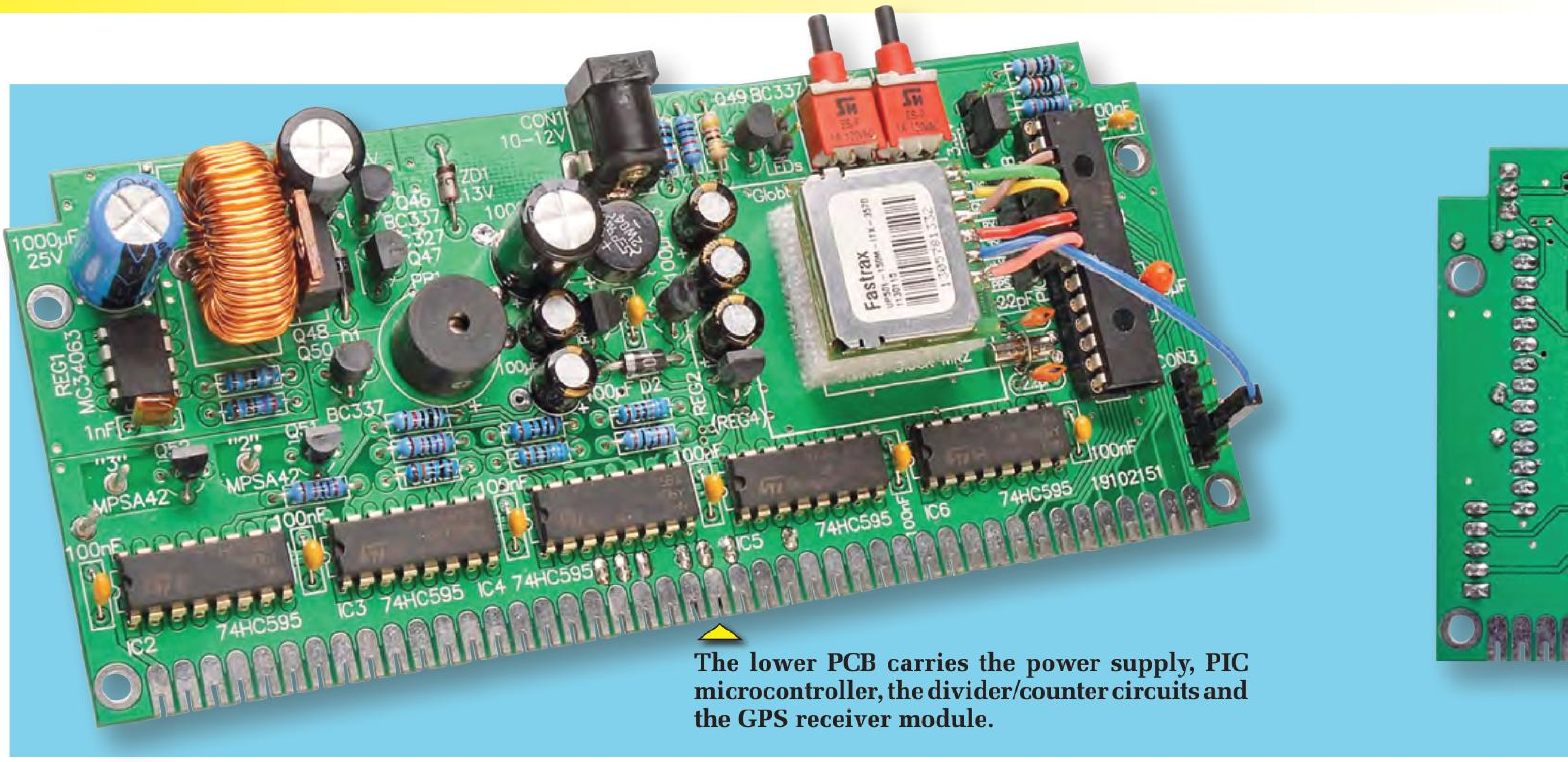
Regardless, be careful with the orientation – ensure that the notched end of the IC or socket goes to the top (IC1, REG1) or lefthand (ICs2-6) end of the PCB. In each case, solder two diagonal pins, then make sure the device is flat on the board and pushed down all the way before soldering the other pins.

Fit crystal X1 next. Bend its leads as shown but make sure they don't touch its case. You can use a component lead off-cut bent into a 'U' shape and soldered to pads on either side of the can to hold the crystal down onto the board as the thin leads can be quite fragile.

The two pushbuttons can go in next, pushed fully down onto the PCB. Follow with bridge rectifier BR1 (watch its orientation) and the remaining TO-92 package devices, ie, Q46, Q47, Q49-Q52 and REG2-REG4. These involve three different



The six blue LEDs are mounted on the underside of the top PCB. Bend their leads at right angles about 3mm from the lens so that they poke up through the holes in the middle of the Nixie sockets.



The lower PCB carries the power supply, PIC microcontroller, the divider/counter circuits and the GPS receiver module.

transistor types and two different regulator types so don't get them mixed up; refer to Fig.3 to see which type goes where. As before, you will need to crank the leads out before fitting them.

Now flip the board over and fit the parts which go on the underside: IRX1, LED1 and LDR1. Fig.4 shows the details. Note that LED1's and LDR1's leads are bent down by 90° just behind the main body of each part. They are then fitted so that they hover just under the PCB (but not touching it). IRX1 should be pushed all the way down onto the PCB before being soldered.

IRX1, LDR1 and LED1 are all oriented so that their lenses face the adjacent edge of the PCB. Make sure LED1's anode (longer lead) goes through the hole marked 'A'. The orientation of the LDR is not important. Leave off the supercap for now.

As shown in Fig.4, you also need to cut and glue a piece of black card between LED1 and IRX1. This is to minimise the amount of light from the LED which reflects off the inside of the front panel of the case and straight back onto IRX1.

Cut a 10 × 20mm piece of card and glue it as shown in Fig.4. We used hot-melt glue, but neutral-cure silicone sealant would be a better choice.

You can check that the card is correctly placed by temporarily fitting the short spacers to the underside of the PCB and dropping it into the case. The card should sit on (or hover just above) the base and should also be in contact with the front side of the case, or very nearly so. If it's pressing on the case you can trim it for a better fit.

Now go back to the top side of the board and install the 11 ceramic/plastic-film capacitors, followed by the seven electrolytic capacitors in the locations shown in Fig.3. Note that the electrolytics are polarised.

The electrolytics all go in the same way except for the two near the upper-lefthand corner of the PCB, which go in the other way around. Just be sure to orient them as shown on Fig.3.

The remaining tantalum/SMD ceramic capacitors can go in now. If you're supplied with a tantalum, this is polarised just like the aluminium electrolytics and will have a plus symbol printed on it. This goes towards the top of the board.

If using an SMD ceramic instead, solder it to the pads on the top of the board; the orientation doesn't matter.

Now fit the pin headers for LK1, CON2, CON6 and optionally CON5. Follow with DC socket CON1, then install the piezo buzzer (PB1) with its positive terminal towards the bottom of the PCB – see Fig.3. If it has a protective sticker on top, peel it off now.

You can now mount toroidal inductor L1. Ideally, it should be glued to the PCB with some silicone sealant – although the board likely won't be subject to much vibration so you can get away without doing this.

Time zone enhancements

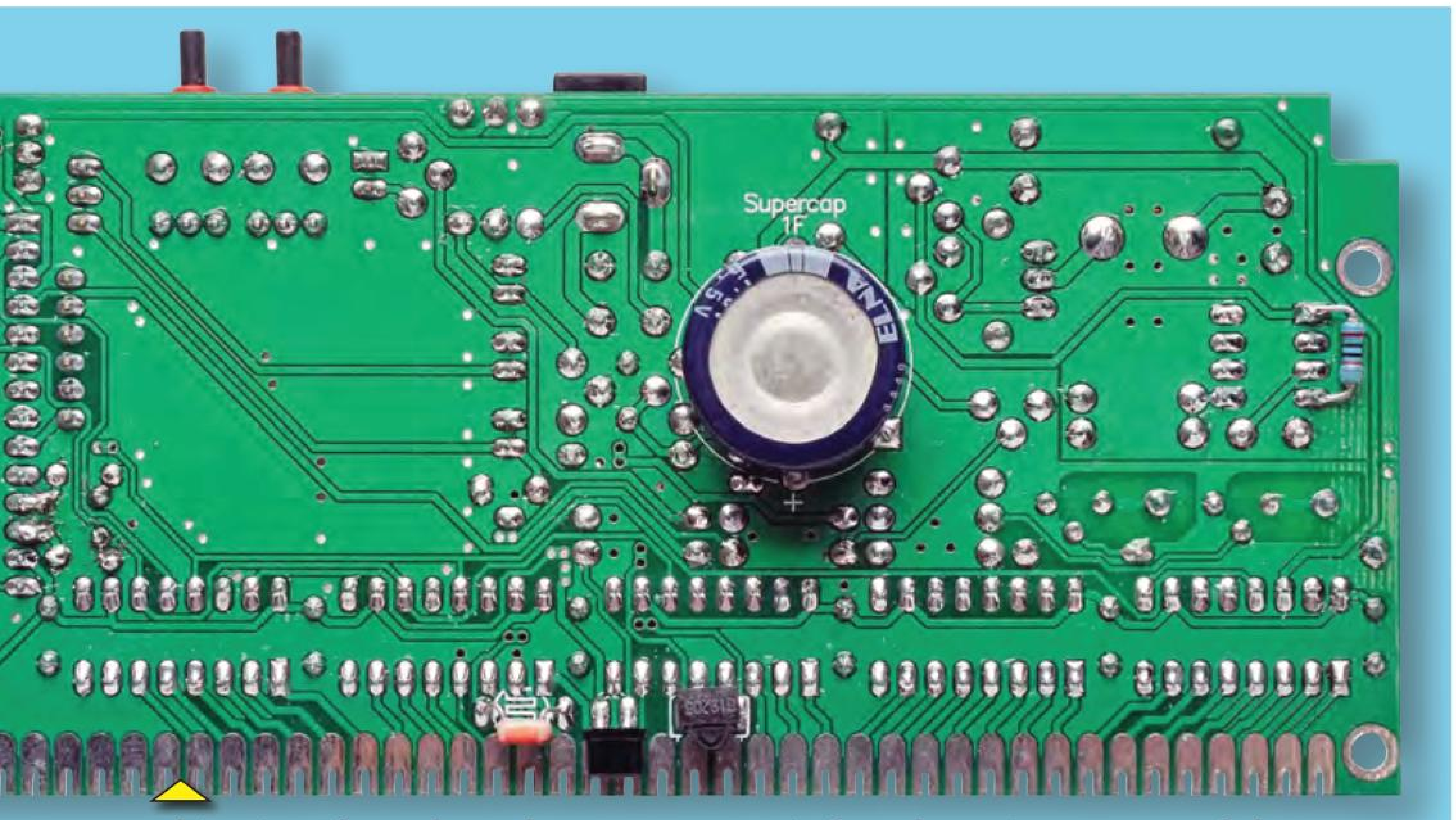
In the article last month, we gave a list of regions where the time zone and daylight savings rules would be automatically determined. Since then, we have been able to add much more time zone data. As a result of the now near-global coverage, the unit should be able to determine the correct time zone just about anywhere on Earth.

The resulting compressed time zone database is just shy of 200KB, so it comfortably fits in the PIC32's 256KB flash.

We realise that few constructors will require global coverage as most will live in Australia, New Zealand with maybe a few in the UK, Canada and the USA. So you may wonder why we bothered doing the extra work. The reason is that a global time zone database that fits in a microcontroller seems like a useful thing in general and some readers may wish to use it in their own projects.

As far as we know, this is the first publicly available database (and codebase) to offer global coverage in such a compact package. So by releasing the source code for this project, we've made it much easier for anybody wanting to build a truly global GPS clock using a low-cost, compact microcontroller.

If you're interested, download the source code and peruse it from: https;//github.com/minitz. The time zone data and handling functions should be easy to bring into your own software if you are familiar with the C language.



This view shows how the LDR1, LED1, infrared receiver IRX1 and the supercap are installed on the underside of the upper PCB.

The last part to be installed on the top of the PCB is high-voltage MOSFET Q48. This is soldered in place with its metal tab facing inductor L1.

All that's left now is to mount the super capacitor on the underside of the PCB. There are two sets of holes to suit different types of capacitors; most likely the supplied part will fit the most widely spaced pads (see Fig.4). Make sure the supercap is installed with the correct polarity – its positive lead should be marked and this goes into the pad near ZD1.

Initial power tests

Before going any further, it's a good idea to apply power and check some voltages. If you have a bench supply, set it to 12V DC 500mA, otherwise use the plugpack. **Make sure the board is on a non-conductive surface and keep well clear of the upper-left section while it is powered up and for one minute afterwards. This area of the board runs at 180V DC and it does bite – trust us!**

The current drain will be a few hundred milliamps initially as the supercap charges, but it should eventually drop to a few tens of milliamps, most of this being the quiescent current of the high-voltage boost DC/DC converter.

Check the 3.3V and 5V pins on LK1, using the PCB pin near the lower-left corner of the board as a ground reference. These should both be close to their nominal voltages. Also, check for 3.3V at pin 2 of CON3 at lower-right. Now, without touching any nearby components, check the voltage at the upper-left PCB pin, just to the left of L1. This should be close to 180V DC.

Switch off and wait one minute for the HV capacitor to discharge. Measure the high voltage pin again, as explained above and ensure it's below 20V before proceeding.

Assuming the voltages are all OK, you can finish the construction. Otherwise, check for correct component placement and orientation and for good solder joints, then repeat the tests.

Fitting the GPS module

If you're building the GPS-locked version of the clock, it's basically just a matter of running five or six wires from the module to CON7 and then attaching the module to the PCB.

First, identify the connections on your module. Connections for a few common types of GPS receiver are shown in Fig.5. Be careful to check which is pin 1 since the pin ordering will depend on the orientation of the module, ie, if you flip it over, the wiring order will be reversed.

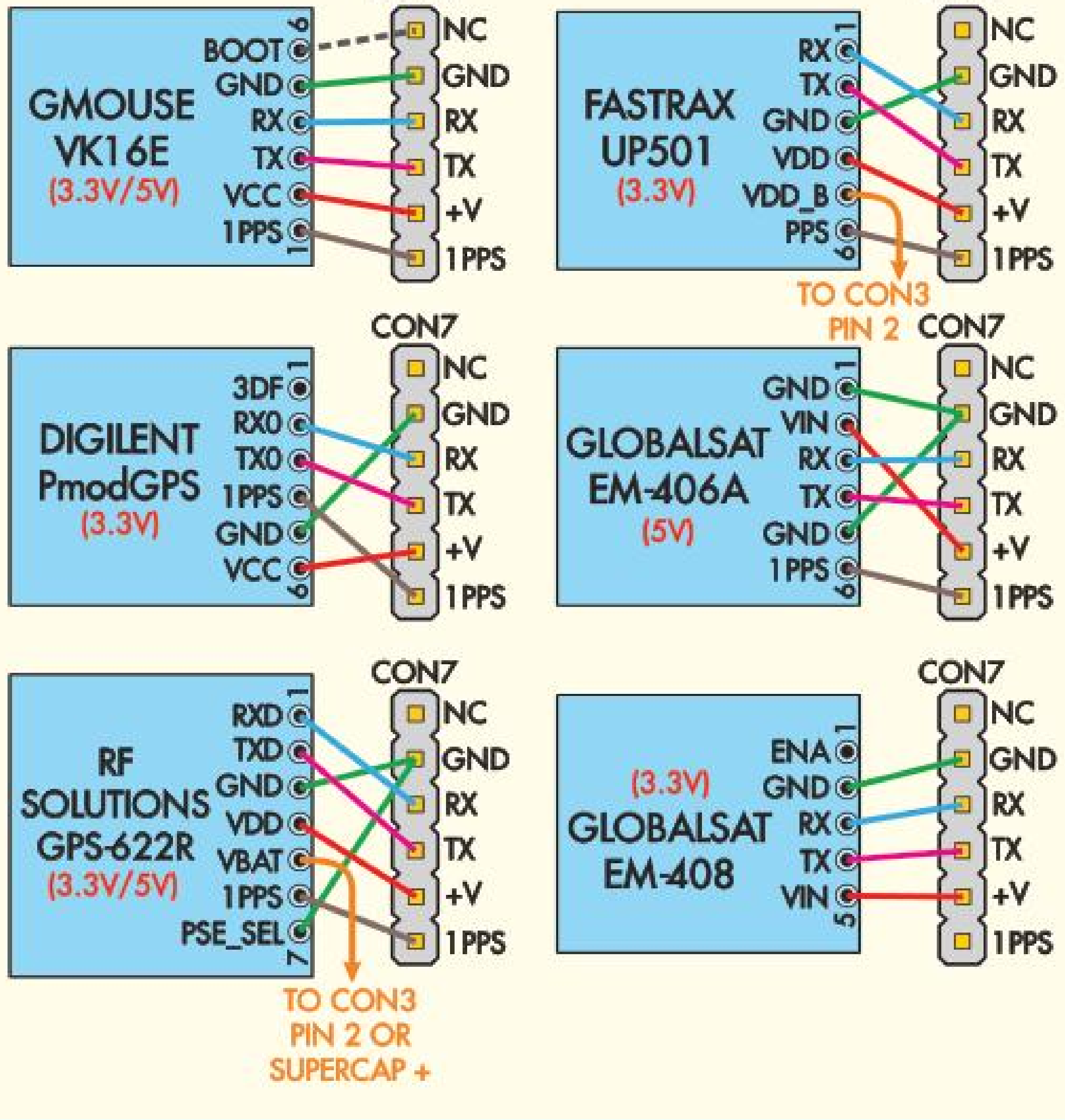
If your module is not shown in Fig.5, refer to its data sheet. If there is a BOOT or ENA (enable) pin, determine whether it needs to be left floating or connected to GND or V_{DD} for normal operation. If there is a V_{DD_B} pin, check that the 3.3V back-up supply at pin 2 of CON3 will be suitable; in most cases, it will be. The module's RX terminal goes to the pin labelled RX (pin 2), ie, this is labelled for the module and not for the micro.

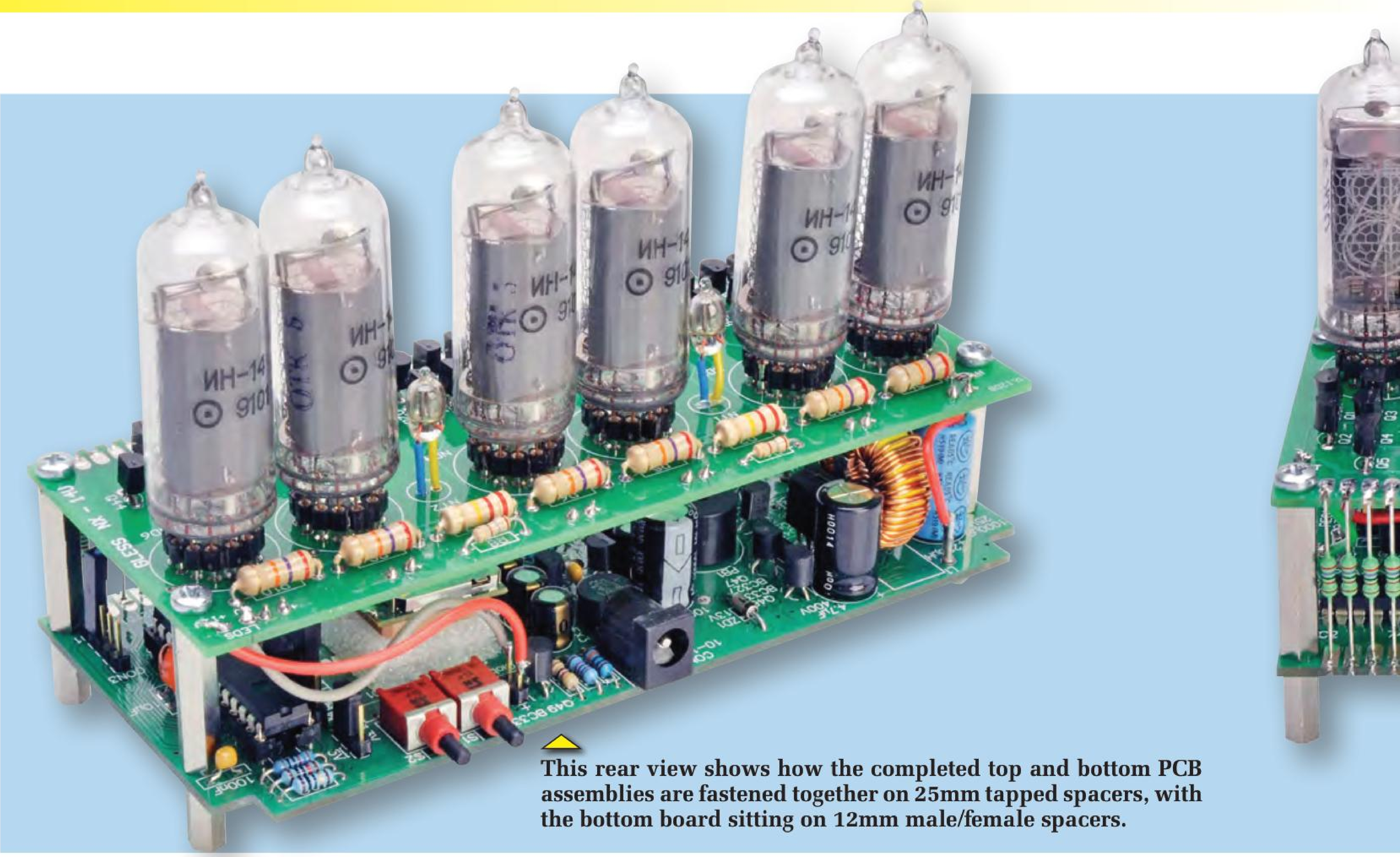
Most modules will either be supplied with a cable that plugs into a small onboard header or else will have a row of solder pads. If it came with a cable, cut it short, to about 22mm and strip a couple of millimetres of insulation off the end of each wire before tinning it. Otherwise, you will need to cut a similar length of ribbon cable and solder one end to the row of pads, with bare tinned wires at the other end. If there is a V_{DD_B} wire, make it substantially longer than the others, at around 50mm, so it can reach pin 2 of CON3.

There are two options for making the connections. You can either solder the bare wires directly to the pins of CON7 or you can attach a pin header plug (or cut up a cable with a header already attached). A plug obviously makes it easier to remove the module later, however this is not normally required and it's certainly quicker to solder them direct.

In theory, the GPS module should be oriented with its ceramic patch antenna facing up. However, we experimented with both orientations and

Fig.5: how to wire up various GPS modules. Take care with the pin 1 orientation and note that the wiring shown for the UP501 is different from that shown in Fig.3. That's because we're showing the UP501 with its antenna facing down in this diagram but facing up in Fig.3. Also note that VK16E's BOOT pin may be left unconnected and the GPS-622R's VBAT pin can go to either CON3 (as for the UP501) or directly to the supercap positive terminal, which would give a longer ephemera retention time.





This rear view shows how the completed top and bottom PCB assemblies are fastened together on 25mm tapped spacers, with the bottom board sitting on 12mm male/female spacers.

Adjusting for accurate timekeeping without GPS

Assuming a relatively stable ambient temperature, the unit can be adjusted to be out by less than one second per month. The easiest way to do this is as follows:

(1) Set the time using an accurate reference such as the speaking clock service. Make a note of the date that you do this. You don't have to set the clock to be precisely correct, as long as you know how much it's off by. If it isn't precise, make a note of the number of seconds error. For example, if you've set the clock to say 09:00:00 at 9:00:02am on 15 March, the error is –2 seconds.

(2) Leave the clock for some time – a week is sufficient but longer is better.

(3) Using the same accurate time source you used earlier, compare the time on your clock to this more accurate time source. So, for example, let's say your clock reads 10:08:33am but the speaking clock service says it's 10:08:12am on 23 March. The error is now –21 seconds. Note this and also the current date.

(4) Subtract the first error from the second error. In this case, the result is –19 seconds. If the time was set precisely during the first step, this will not affect the error noted in step three above.

(5) Determine the number of days that have passed between steps one and three. In our example, it's eight days (23 –15).

(6) Multiply the error from step four by 1024, then divide by the number of days from step five and divide again by 45. The result in this case is –21 x 1024 ÷ 8 ÷ 45 = –59.7 which we round to -60.

(7) Go into crystal frequency trim mode (see panel on control interface) and add the number calculated above to the reading. So, in this case, if the current reading was 500, you would need to adjust it to give 440 instead. Save the changes and that should cancel out most or all of the error.

(8) If you notice over many weeks or months that the clock is slowly gaining or losing time, adjust the trim value in single steps. Make it higher if the clock is falling behind or lower if the clock is going too fast.

found that it made little difference to sensitivity.

If soldering the wires directly to CON7, mount the module first. Otherwise, once the plug has been wired up, plug it in and then mount the module. Smaller modules such as the Fastrax UP501, GlobalSat EM-406A and VK16E can be fitted directly on top of the PCB using some double-sided tape.

However, in practice, it's preferable for them to be further away from the ground plane, so it's better to attach them using a non-conductive spacer. Larger modules will require a spacer to clear surrounding components.

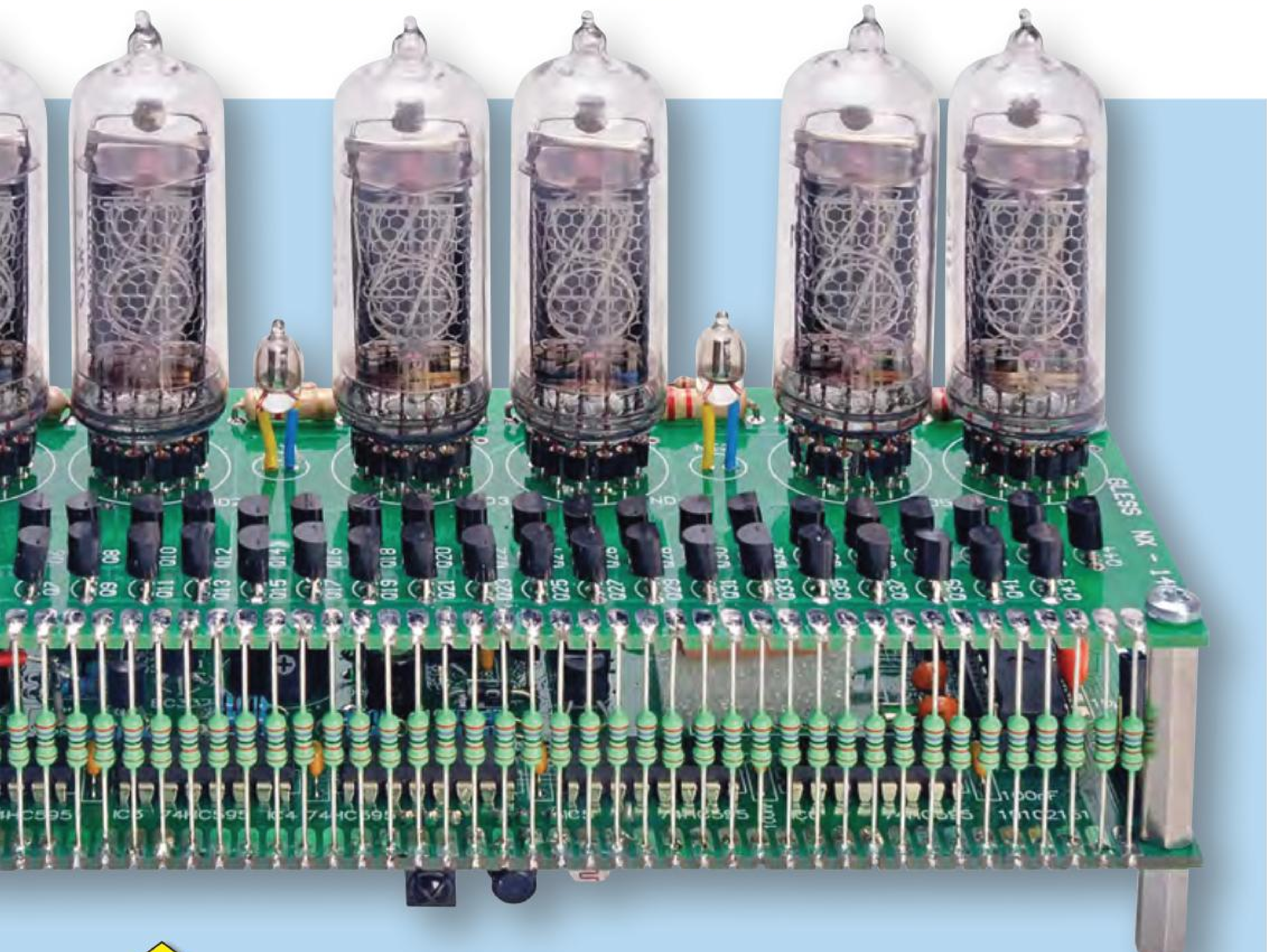
The spacer can be made from plastic or a non-conductive type of stiff foam and attached to the board and the module itself using double-sided tape. Use multiple layers of plastic if necessary to create a thick enough spacer.

We used polyethylene foam since we happened to have some handy, but a more rigid material is better.

Once the GPS module is in place, fit the shorting block to LK1 to set the required supply voltage (3.3V or 5V).

Joining the two boards

Now plug IC1 into its socket. You will probably need to straighten its pins first. Make sure that the pins all go



Above: the 44 × 27kΩ resistors are strung between the two PCBs and soldered to slotted solder pads along the front edges. Make sure that the resistor leads are straight and use a ruler to ensure that they line up neatly (see text).

into the socket. Also, plug in the other ICs if using sockets for them as well.

The next step is to cut two 60mm lengths and four 40mm lengths of mains-rated medium-duty hook-up wire. Strip and tin both ends, then solder one end of each to each of CON11-CON15 from the underside of the upper PCB. The two longer wires are for CON13.

Now place the upper board upside-down behind the lower board (right-side up) and solder the wires to the PCB pins (CON5, CON6, CON8 and CON9) and 2-pin header (CON2) on the lower board as shown in Fig.3. It's easiest to start at the back and work your way to the front of the lower board. Make sure the wires to CON2 aren't reversed or the LEDs won't light up.

Having done that, fit a 12mm male/female tapped spacer to one of the mounting holes on the lower board from the underside, then attach a 25mm tapped spacer on the top side. Do this up tight, then repeat for the other three mounting holes. You can then fasten the two boards together using four M3 x 6mm, pan-head screws. Do these up firmly and make sure the six wires are still connected at both ends and neatly tucked away.

The next step is to fit the 44 27kΩ resistors into the slots along the front of both boards. It's important that the bodies of these resistors are lined up carefully so that the finished clock looks neat. The following procedure is recommended. Try to avoid bending the resistor leads when removing them from the strip they are supplied on.

Take two resistors with nice, straight leads and insert them into the pair of slots at the far left and far right ends of the boards. Next, use a small ruler to measure the distance between each resistor's body and the top and bottom boards and move the resistors up and down until those distances are equal. Solder one end of each device, then check that the each resistor is still centred properly before soldering its other end.

That done, insert another resistor between two slots near the middle (make sure the slots correspond!) and place the ruler horizontally so that it lines up with the bottom of the resistor bodies at either end. Adjust the middle resistor so it too is aligned with the ruler and solder it in place using the same method as before.

Now continue by placing two more resistors between the three already soldered in, and keep 'bisecting' in this manner until all the resistors are in place. This method gives you the best chance of getting them all to line up without the gaps increasing or decreasing as you go.

Once they're all in place go back over all the solder joints and make sure they have sufficient solder and have flowed properly before trimming off any excess lead length remaining.

More testing

The Nixie tubes can now be unpacked and plugged into their sockets. Before plugging them in, you will need to remove the plastic spacer and carefully trim the leads to exactly 5mm long, measured from the glass base of the tube. Make sure the leads are all straight, then gently place one tube on top of one of the sockets with each lead sitting in the cup of its socket pin.

Now slowly push the tube into its socket. If any of the pins are not properly in the socket or if any starts to bend during insertion, remove the tube and fix that pin, then try again. It should go in with gentle pressure.

Fit the other five tubes in a similar manner, then make sure the whole assembly is clear of any conductive items such as loose bits of wire and solder. With the plugpack disconnected from the mains, plug it into CON1, then keep yourself clear of the board assembly while powering it up.

Be careful during testing: as stated, the HT supply is around 180V DC and it can give you a nasty shock if you come into contact with it! Don't touch or work on the unit when the plugpack is connected.

In addition, wait 15 seconds for the 10µF 250V capacitor to discharge after switch off before touching the unit. It should be safe once the neon lamps have gone out, but if in doubt, measure the HT voltage rail.

The *Nixie Clock* performs a display test initially, so you should see all six zero segments light up, followed by one, two, three etc. **Note that the first, third and fifth tubes will only display digits up to three, five and five respectively so don't be concerned that they do not light when the other tubes are showing six, seven, eight or nine.**

The unit should also emit a short beep briefly after power is applied, verifying that the piezo buzzer works.

Having gone through the digit test, you will then see a display of '00.00.00' with the first digit flashing, indicating that the time has not yet been set. Check that the blue LEDs are lit.

Using the control interface

The clock is set up and controlled using the two rear-mounted pushbuttons and the front proximity sensor. We refer to the pushbuttons as ‘left button’ and ‘right button’; this is the orientation when the digits of the clock are facing you. Below, we talk about short and long presses. A short press is under one second (typically, 250-500ms) while a long press is for more than one second. Some actions require the buttons to be pressed simultaneously.

A number of settings are stored in the microcontroller’s Flash memory, so they are effectively permanent, even if power is lost for long periods. These are: LED status (blue LEDs on/off), 12/24 hour time setting, leading zero blanking setting, timing crystal trim value, alarm time and days, time zone (if a GPS module is fitted) and LED/Nixie dimming settings.

The various actions that can be performed using the buttons are:

- **To turn blue LEDs on/off:** press both buttons, then release simultaneously after a short duration (around half a second).
- **To set time and/or date (no GPS fitted):** long press left button. Time is frozen and one digit flashes. Short press left button to increment digit, short press right button to move to next digit. To switch between setting time and date, long press right button. When finished setting, long press left button.
- **To set the time zone (GPS fitted):** long press left button. Flashing ‘00’ indicates automatic time zone and daylight saving mode. Short press left/right buttons to change to manual mode and set time zone offset in 15-minute intervals. With time zone set manually, daylight saving is disabled. Long press left button to save changes, long press right button to abort. To go back to automatic TZ/DST, go into time zone setting mode and press left/right button until flashing ‘00’ is displayed again.
- **To switch between 12-hour time and 24-hour time:** go into time set or time zone set mode (long press left button), then hold down both buttons for at least one second and release simultaneously.
- **To show the date:** short press left button or briefly place your hand close to the proximity sensor at the lower front of the unit (within a few centimetres of the case).
- **To set alarm:** long press right button. Set alarm time using the same procedure as outlined for setting the time above. By default, alarm sounds during week days only. To change, long press right button. Days are shown as 0123456 with 0 = Sunday, 1 = Monday, etc. Days for which alarm is enabled are lit, disabled days are off. Short press left button to toggle alarm setting for current (flashing/pulsing) day. Short press right button to move to the next day. Long press right button to return to setting alarm time; long press left button in either mode to save settings and enable alarm.
- **To show alarm time:** short press right button. Alarm time is shown for 10 seconds, then it goes back to displaying the current time. If alarm is on, display during this time is solid, otherwise it flashes.
- **To turn alarm on/off:** show alarm time as described above, then short press left button to toggle alarm on/off.
- **To cancel/snooze alarm:** trigger proximity sensor (as described above for date display) for 10-minute snooze. Short press either button to cancel alarm.
- **To trim out crystal frequency error (not required when GPS module fitted):** hold down both buttons for at least one second, then release simultaneously. Adjustment is initially 500; higher values (up to 999) make clock run faster, lower values make it run slower. Short press left and right buttons to reduce/increase trim value. Long press left button to save changes, long press right button to abort. See accompanying panel for how to determine the correct value.
- **To enable or disable leading zero blanking (generally used in 12-hour time mode):** go into crystal trim mode (see above), then after releasing buttons, hold down both buttons again for at least one second and release simultaneously. By default, leading zero blanking is not enabled, so this will enable it. Use the same procedure to turn it off again.
- **To enable or adjust auto-dimming:** both the Nixie tubes and the blue LEDs can be set to automatically dim as the ambient light level drops (as sensed by the onboard LDR). There is a dimming factor value for each. If set to zero, they will always operate at full brightness. For numbers greater than zero, larger numbers mean faster dimming as the ambient light level drops, up to a maximum value of 20, with a default value of eight. To set the LED dim factor, hold down the right button for at least one second, then press the left button and quickly release both. The left and right buttons are then used to change the value with a long press of the left button to exit. Setting the Nixie tube brightness is identical but reverse the initial long/short button presses (ie, hold down the left button then briefly press left).

If anything goes wrong, switch off and check the assembly for faults. If one or more segments are not lighting, first check that the tube is inserted properly in the socket and that the resistors along the front of the unit are all soldered properly. Otherwise, it could be a suspect solder joint on one of the ICs.

If you don’t get any display, that suggests a problem with IC1 or its associated crystal oscillator. Nothing will function if the oscillator isn’t working. If the neon lamps don’t light, that suggests a problem with the boost generator or wiring as they are permanently wired across the HV rail.

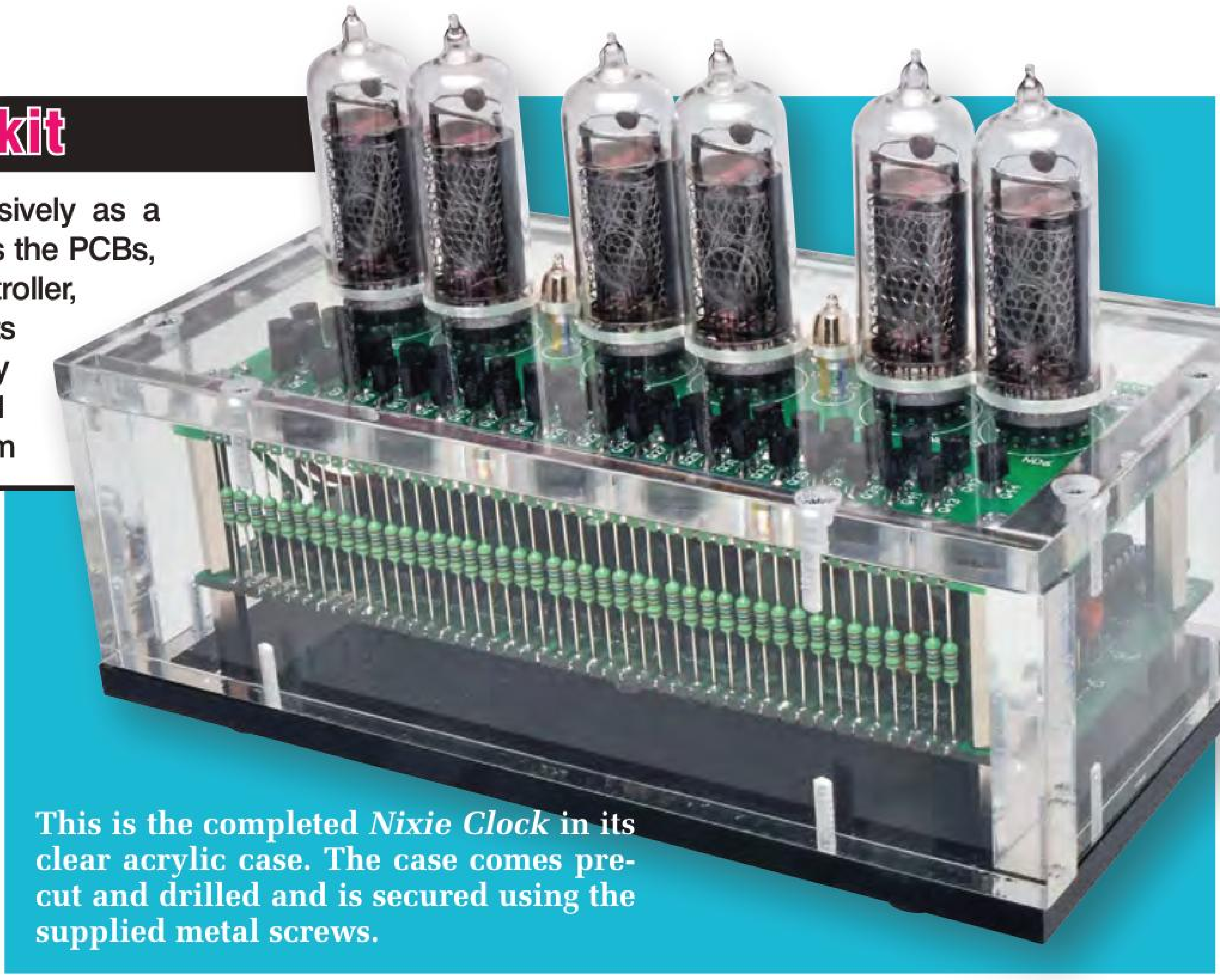
If it checks out, switch off and wait 15 seconds after the neons go out before touching the board assembly.

Putting the case together

The case is made from six pieces of acrylic, one black and five clear, held together with 16 self-tapping screws which go into pre-drilled holes. Start by attaching the thicker clear front and side panels to the base panel using six of the supplied self-tapping screws. Next, attach the thinner clear rear panel to the sides with four more screws.

Where to buy a kit

The *Nixie Clock* will be available exclusively as a complete kit from Gless Audio. It includes the PCBs, all components, a programmed microcontroller, Nixie tubes and the case hardware. Kits should be available late February/early March 2015. Contact Gless Audio: +61 (0)403 055 374 or email glesstron@msn.com



This is the completed *Nixie Clock* in its clear acrylic case. The case comes pre-cut and drilled and is secured using the supplied metal screws.

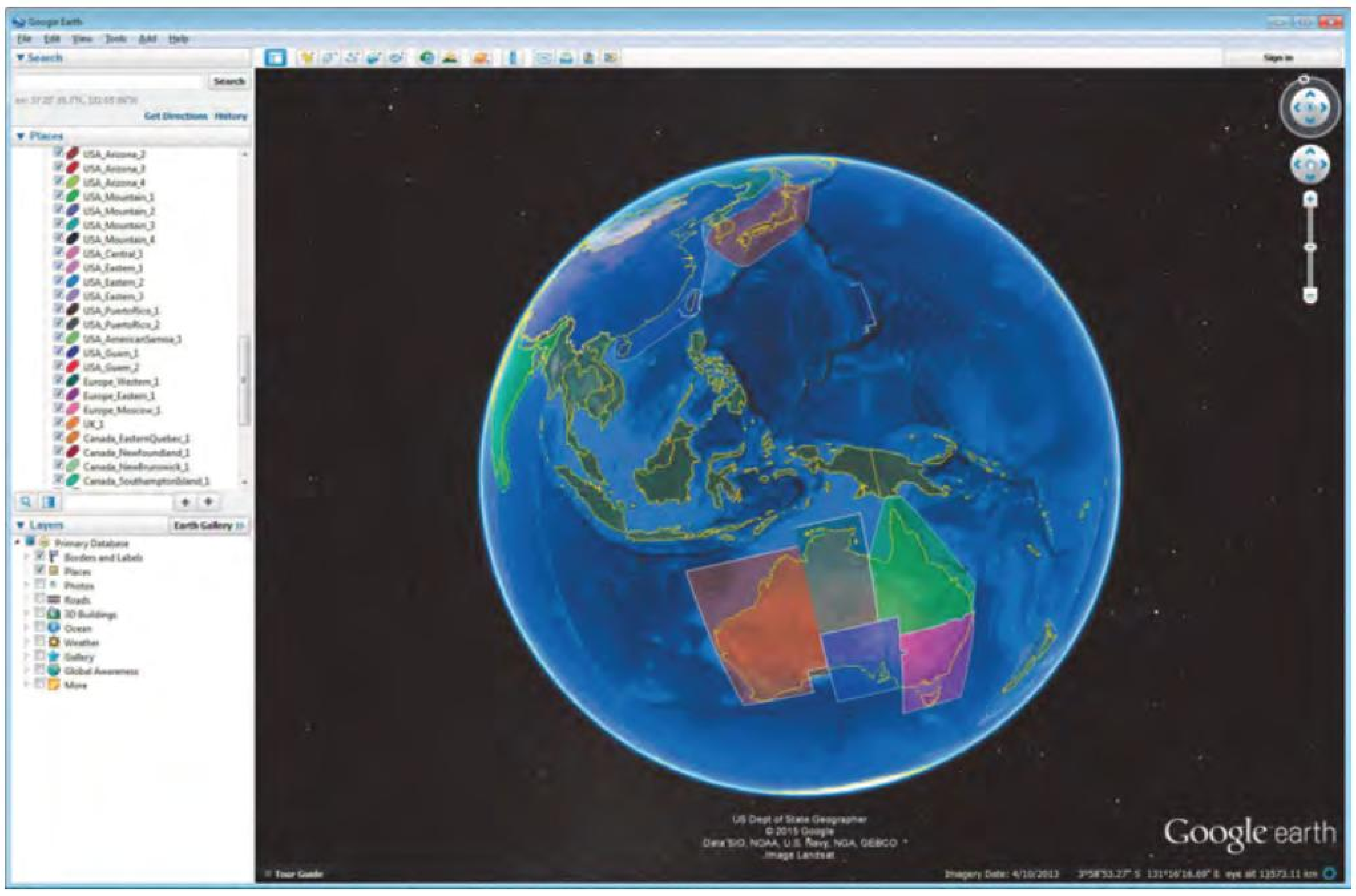


Fig.6: a Google Earth view showing some of the time zone regions used to calculate local time. These shapes have been simplified as much as possible, to save Flash memory storage space, without compromising the accuracy of determining the correct zone for any latitude/longitude on land. For example, where they overlap, only the border of the time zone analysed first has to be accurate as areas within this zone are excluded before the latter zone is checked.

You can now affix the feet to the base. Position them horizontally just within the PCB mounting holes, 5mm from the front edge of the base and 10mm from the rear edge.

Now temporarily remove the Nixie tubes from the PCB assembly before lowering it into the case, positioned towards the front. Once it's resting on the base, slide it back so that the pushbuttons pop through the routed access slot at the rear. You can then secure the whole thing in place using four M3 pan-head screws up through the mounting holes in the base. Do them up nice and tight.

Now fit the lid using the six remaining self-tapping screws. Once it's in place, you can carefully plug the Nixie tubes back in.

Final testing and operation

With everything now inside the case, re-apply power. If you've fitted a GPS module, the display brightness will vary in a pulsating fashion until a position fix has been obtained. If you don't get a fix after 30 minutes or so, try moving the unit to a less obstructed position, such as near a window. If the fix is lost, the unit will switch over to using its own crystal and the brightness will pulsate until it again has a reliable GPS fix.

If you aren't using a GPS module and the time has not yet been set, refer to the panel titled 'Using the Control Interface' for instruction on using the two rear panel pushbuttons to set the time. When first powered up, the unit is already in time set mode, so it isn't necessary to hold down the lefthand button to get into that mode. Don't forget to set the date, too.

Once that's done, you can check the operation of the proximity sensor. We've made it relatively insensitive to prevent false triggering so you will need to place your hand up close to the front of the unit, possibly touching it. If nothing happens, try moving it closer to the sensor. Once it's triggered, you should see the display change to show the date and then go back to time after 10 seconds.

You can now set up the various preferences to your liking. Refer to the instructions in the accompanying panel for turning the LEDs on/off, choosing 12/24 hour time and enabling leading zero blanking. If you are using the crystal for timekeeping (ie, no GPS) you can also start the calibration procedure as explained in that panel and there are instructions for setting the alarm if required.

Note that the alarm can be put into a 10-minute snooze using the proximity sensor, but a press of either one of the rear panel buttons is required to actually shut it off when it sounds.

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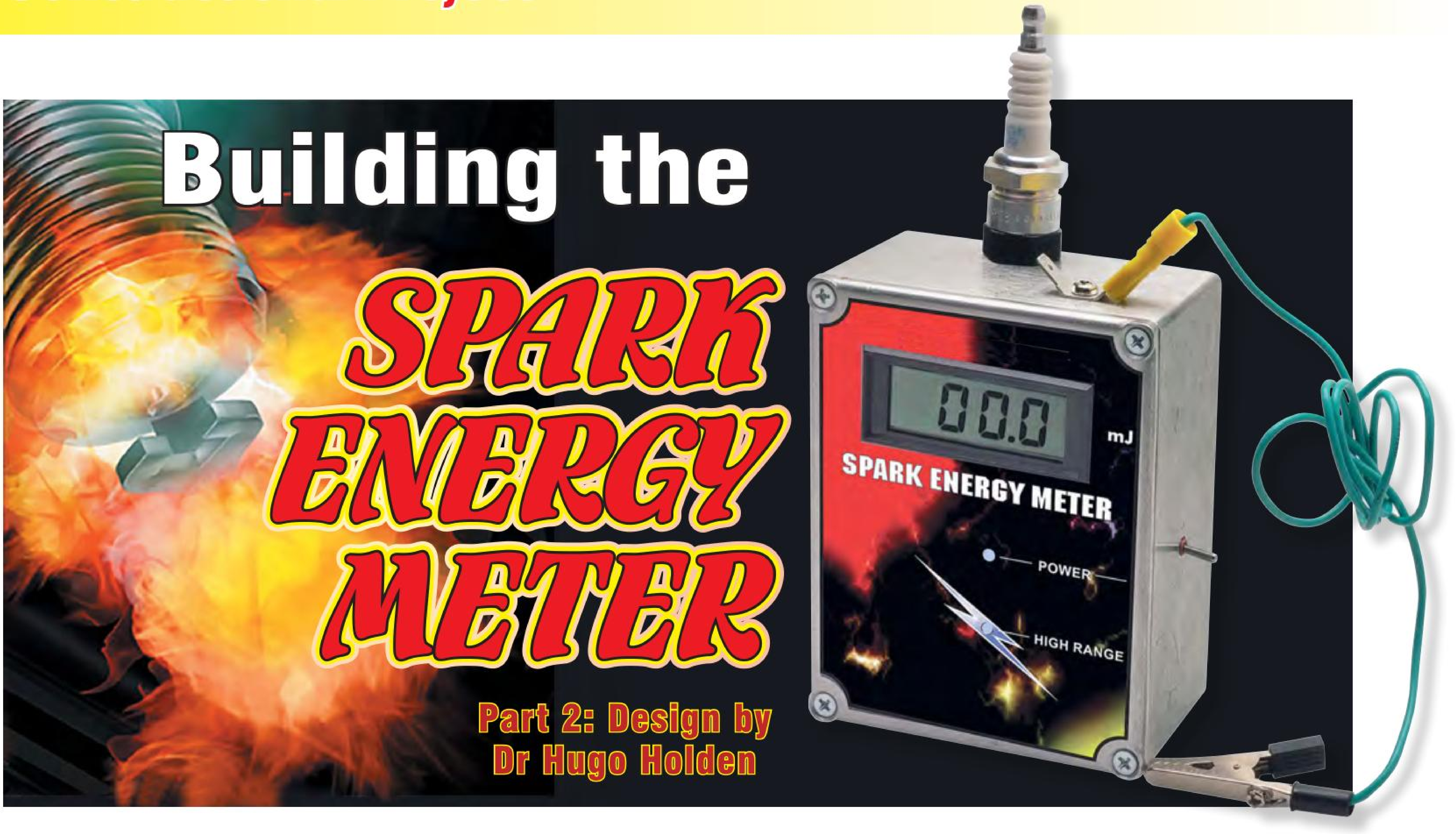


Building the SPARK ENERGY METER

Part 2: Design by Dr Hugo Holden

Last month we introduced our new *Spark Energy Meter*, an essential workshop tool for anyone who tinkers with automotive ignition systems – old or new! Now we get to the good bit: putting it all together . . .

The *Spark Energy Meter* is built on two 111 × 85mm PCBs, which stack horizontally inside a 119 × 94 × 57mm diecast box using 9mm spacers.

The first board, coded 05101151, contains the majority of components, with the exception of the 30 × 100V zener diodes – these are all on the second board, coded 05101152. Both boards are available as a pair from the *EPE PCB Service*.

A power switch protrudes out from the side of the box, while the power LED and high-range LEDs pass through the lid. The LCD is also attached to the case lid.

Before you start assembly, place the zener diode PCB centrally in the bottom of the diecast box and mark the positions of the four 3mm holes used for mounting. You can drill these holes now or later.

Construction

The complete parts list (along with the circuit diagrams and descriptions) were included in Part 1 last month – refer to that article for all components.

Start by fitting 100V zener diodes ZD1 to ZD30 on the second PCB (see Fig.3). These all face the same direction on the board but the tracks underneath actually connect them with 15 in one orientation and 15 in the other.

The connection to the spark plug is made via an M205 fuse clip. The fuse tab toward the plug bends down and around the edge and under the PCB. The fuse tab toward the zener diodes is broken off by bending this backward and forward repeatedly with a pair of pliers. Just a few times will cause it to break off.

Strip a few mm of insulation from each end of a 200mm-long mains-rated wire and terminate one end into the HV output on the PCB.

Cover the wire in heatshrink tubing, leaving sufficient wire free at the other end for termination into the HV terminal on the second PCB.

Now move onto the other PCB. Fig.4 shows the component overlay. Install the small resistors first.

You may know resistor colour codes, but it's always wise to double check each value with a digital multimeter. Leave the 150Ω, 5W resistor for later.

Diodes are next, and as they're polarised, they need to be installed with the striped end oriented as shown in the overlay diagram. Note that there are several types. D1-D4 are UF4007, D5-D14 are BAT46, D15 a 1N4148 and D16 a 1N5819. Zener diode ZD31 can also be installed now.

Solder the ICs next, with pin 1 toward the top of the PCB (S1 side) in each case. Be sure that the correct IC is placed in each position. REG1 and Q1-Q3 can go in next.

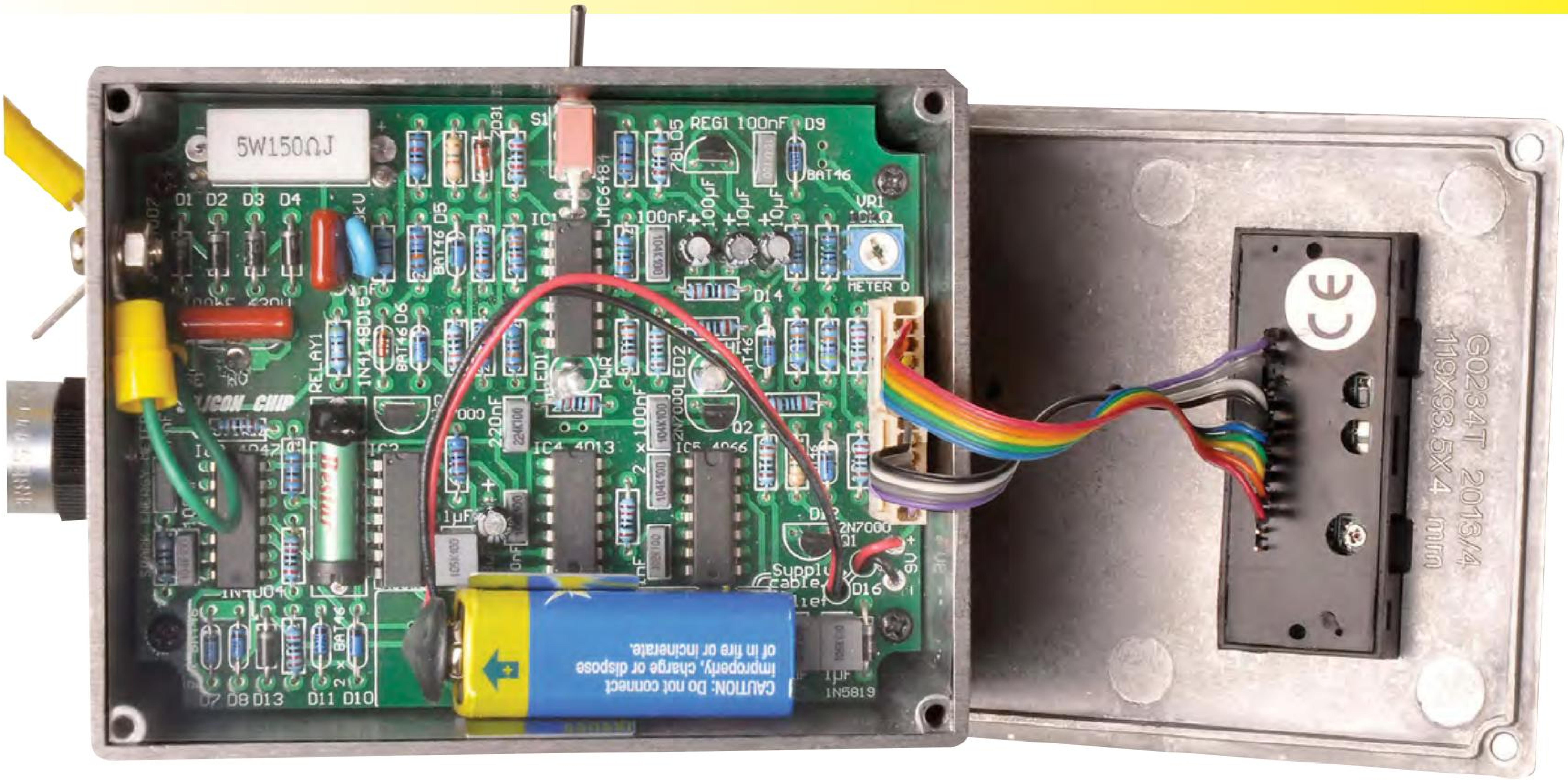
Now fit the capacitors, starting with ceramic and polyester, which of course are not polarised. Note the positions for the 100nF capacitor, the 10nF 630V (or 3kV) and the 1nF 100V (or 3kV) ceramic types.

These have a higher voltage rating than the remaining capacitors. The electrolytic types are polarised and must be inserted the right way around – the longer lead is the + side.

Install the reed relay now, then trimpot VR1. Switch S1 is fitted directly to the PCB and the two 6-way pin headers for the LCD can also be soldered in, along with the two PC stakes and adjacent 150Ω, 5W resistor.

LED1 and LED2 are mounted so that the top of each LED is 31mm from the top surface of the PCB. Take care that the anode (longer lead) is placed in the component hole labelled 'A'.

The 9V battery holder is secured to the PCB using a countersunk M3 screw and nut with a piece of TOP-3 silicone washer between it and the PCB. The washer is trimmed to size with scissors and a hole cut in the centre for the



screw. There will already be a hole in the silicone washer (due to it being punched for the TOP-3 package) but this will be in the wrong position.

Wires for the 9V battery clip are passed through the PCB holes as shown for strain relief, helping to prevent the wires from breaking due to flexing, when terminated to the 9V inputs. The red wire is terminated to the '+' side, black to '–'.

A 70mm length of 7.5A 250VAC mains wire (green or black) is terminated into the 'CASE' terminal and the other end crimped to a crimp eyelet.

Box bits

If you haven't drilled the mounting holes in the box, do so now. If using countersunk screws, ensure you

Producing a great-looking project label!

Nice labels add a professional finish to projects. The label we have prepared (which also doubles as a template for drilling holes and cutting the LCD readout hole) is shown opposite, reproduced same size.

You have several options in making a label:

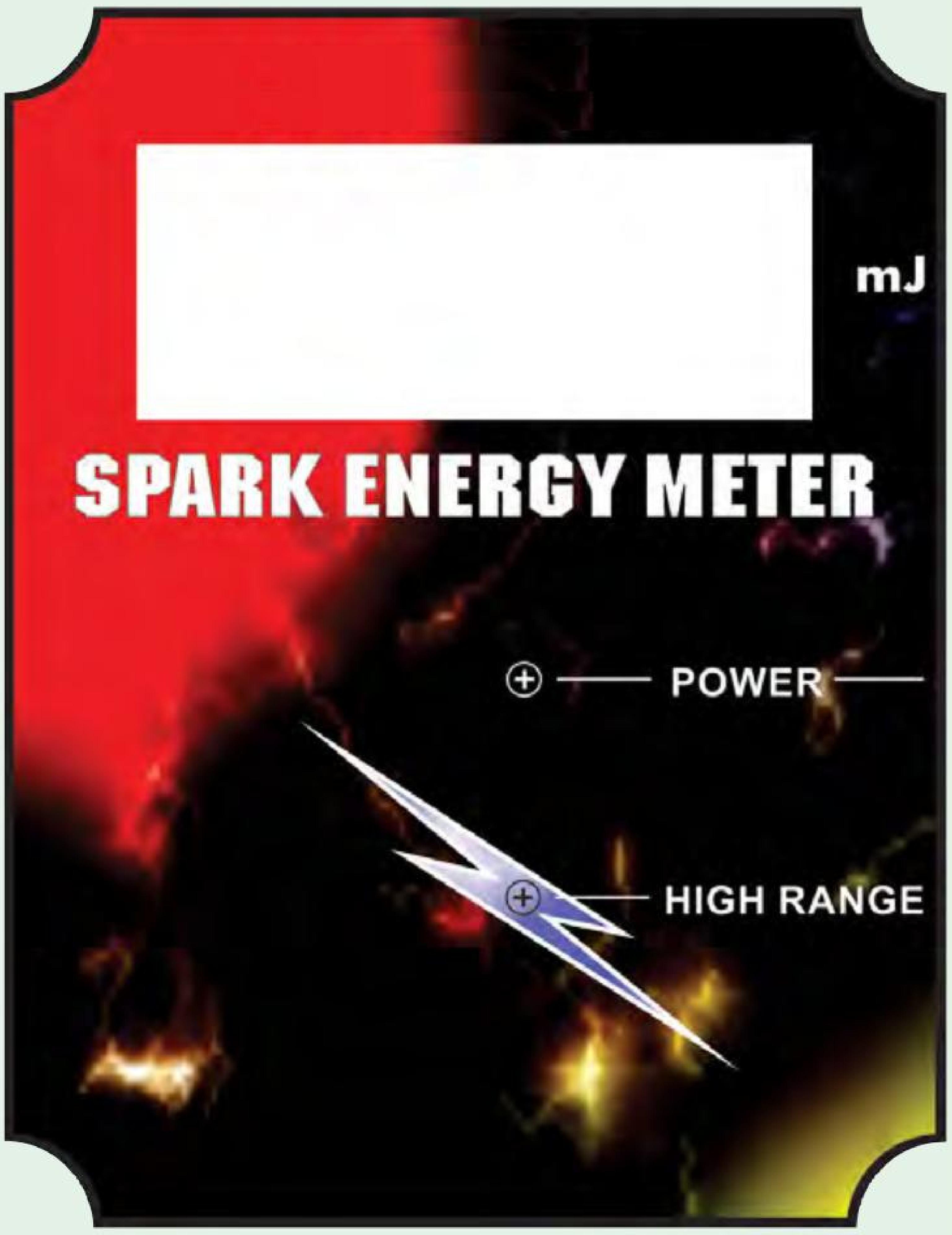
If you have access to a colour photocopier, it can be copied onto paper (either plain paper or photo paper). Or it can be downloaded from the *EPE* website and printed on a colour printer. After cutting out (don't forget the LED holes!) it can be glued to your panel with a suitable adhesive or neutral cure silicone. However, this type of label will be easily damaged. It can be laminated (with a hot melt laminator) although this will tend to separate over time.

For a more rugged label, download and print onto clear overhead projector film (using film suitable for your type of printer) as a 'mirror image', so the printout will be on the back of the film when the label is affixed. Attach with silicone sealant. A light-coloured silicone will be needed if the lid is black.

Another alternative, and one which is arguably the toughest and longest-lasting, is to use a synthetic 'Dataflex' sticky-backed label that is suitable for inkjet printers or a 'Datapol' sticky label for laser printers and affix using the sticky back adhesive already on the label. Cut out the holes in the label with a sharp craft knife.

These labels are available from **www.blanklabels.com.au** and sample sheets are available on request to test these in your printer.

Google 'blank labels dataflex' or 'blank labels datapol' for more information.



Full-size label which can also be used as a template.

countersink the holes on the outside of the box.

Fig.5 shows the hole positions for the spark plug and earth screw hole on the end of the box and the switch hole on the side of the box.

For the spark plug, (which, as mentioned last month, needs to be of the resistor variety) this needs to be drilled smaller than required and then carefully reamed out.

There will be a diameter close to 13.5mm where the spark plug will screw in, cutting some thread but mainly held in place by friction.

Note that the PCB is designed for a spark plug with a 12.7mm reach. If a longer reach spark plug is used (as we did), use a spacer to cover the bare thread that's exposed on the outside of the case. This spacer can be seen in the photo above.

The LCD module is mounted onto the lid of the case. The label artwork, which shows the positioning for the LCD module and the LED holes, also makes a great template. It can be photocopied or downloaded from the *EPE* website (see panel).

The rectangular cut out is made by chain-drilling small holes (2-3mm) inside the perimeter, then knocking out the piece and filing to shape.

The PCBs are attached to the box using 9mm stand-offs. Four stand-offs, held by 12mm × M3 screws, are placed in the base of the case. Next comes the lower PCB, followed by the set of four spacers screwed onto the remaining thread of the screws.

The earth tag on the spark plug that bends around to face the inside insulated electrode is removed. This can be done using pliers to bend the tab back and forth to shear it off. Then file the rough edges down.

Screw the spark plug in to make contact between the centre electrode and the M205 fuse clip on the PCB.

The second PCB stacks on top of the first. This is done after the interconnecting wire between the HV terminals on each PCB is connected. The top PCB is secured with the M3 × 5mm screws. The crimp eyelet is secured to the case with an M4 screw, star washer and nut with the spade connector attached on the outside of the box using the same screw.

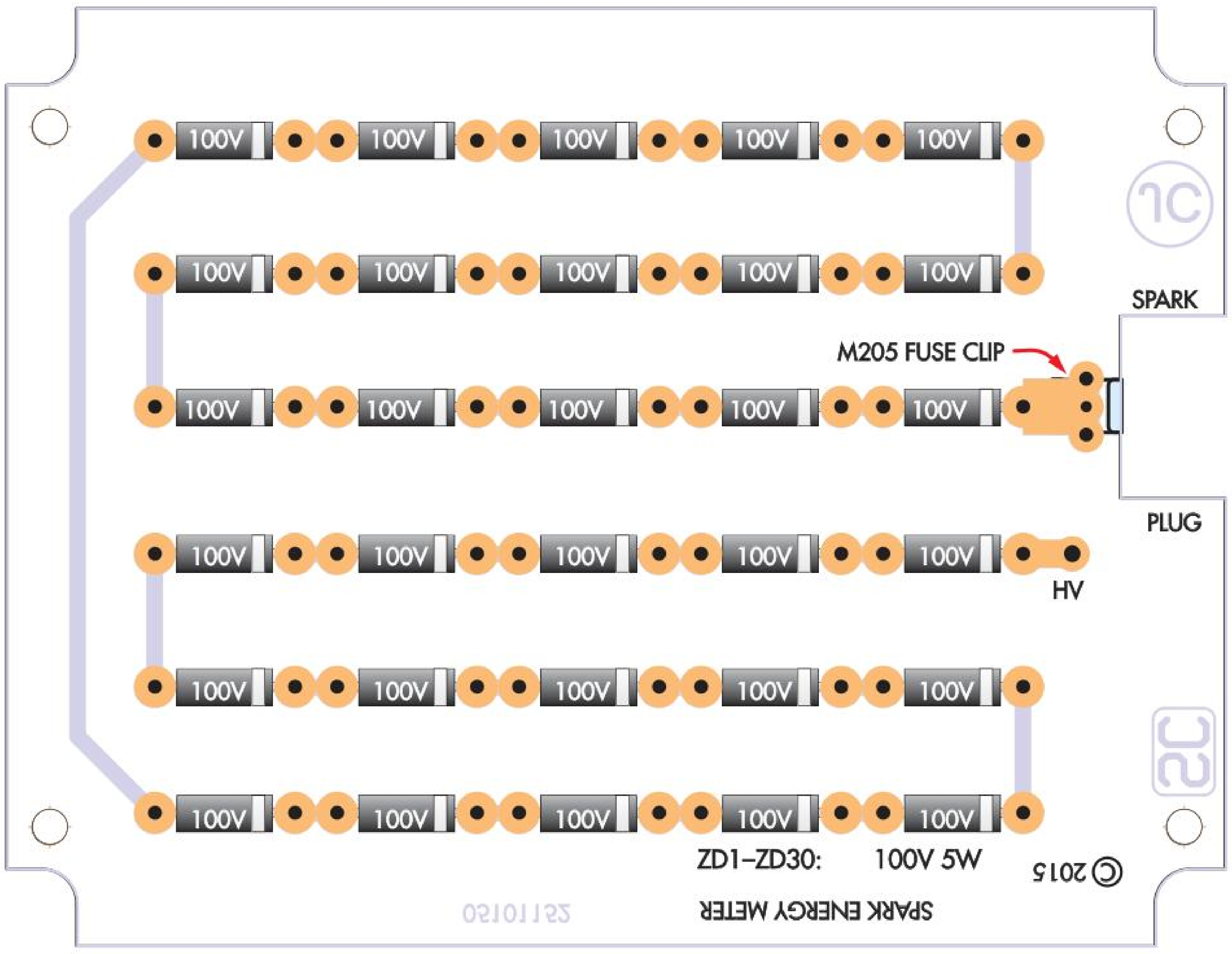
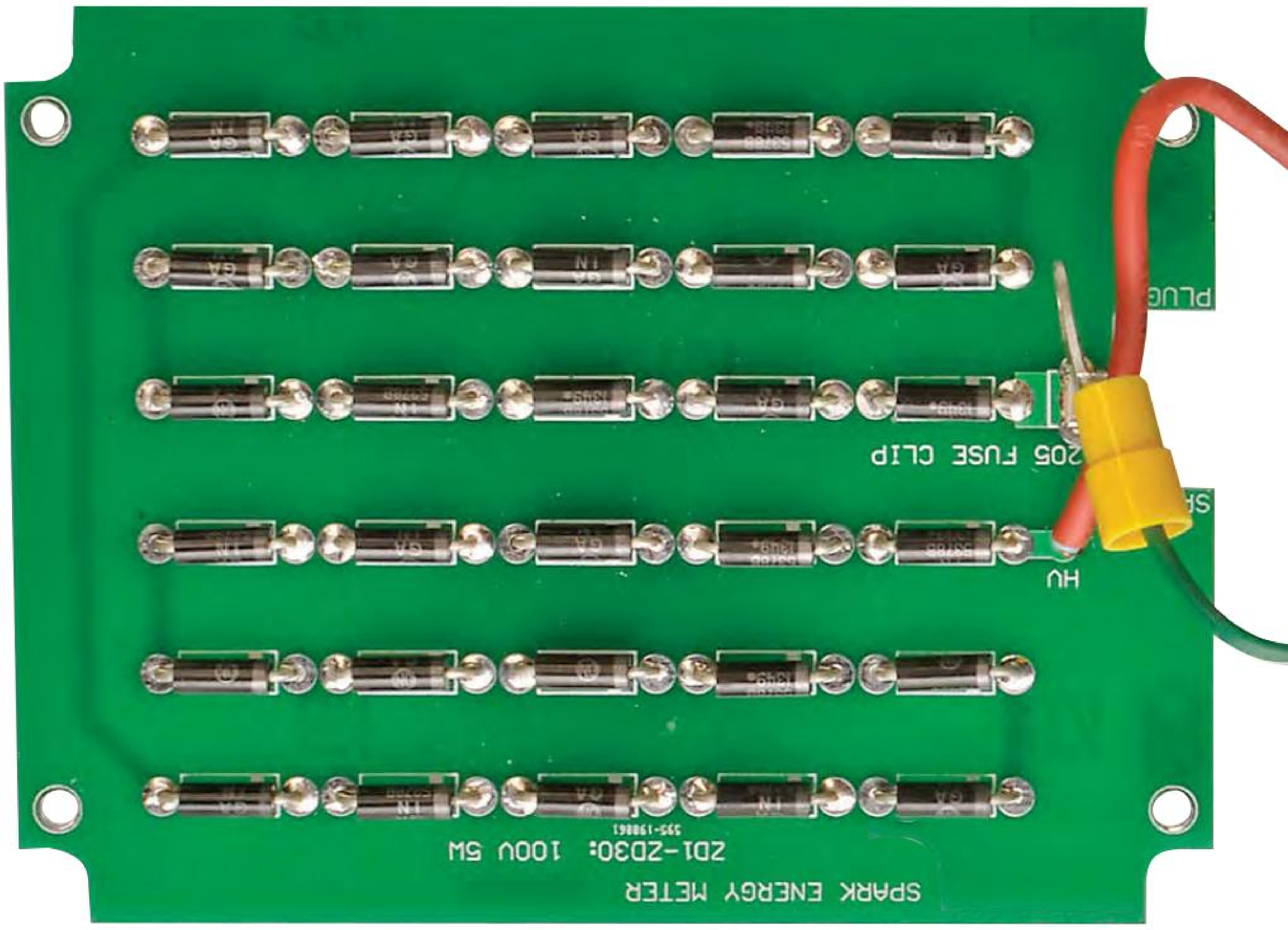


Fig.3 (above) is the component overlay for the zener diode PCB. All zeners are oriented the same direction, so construction is easy! Below is a matching photo of this board, again printed very close to life size. The fuse clip on this board is obscured by the spade lug insulator.



Wiring the display

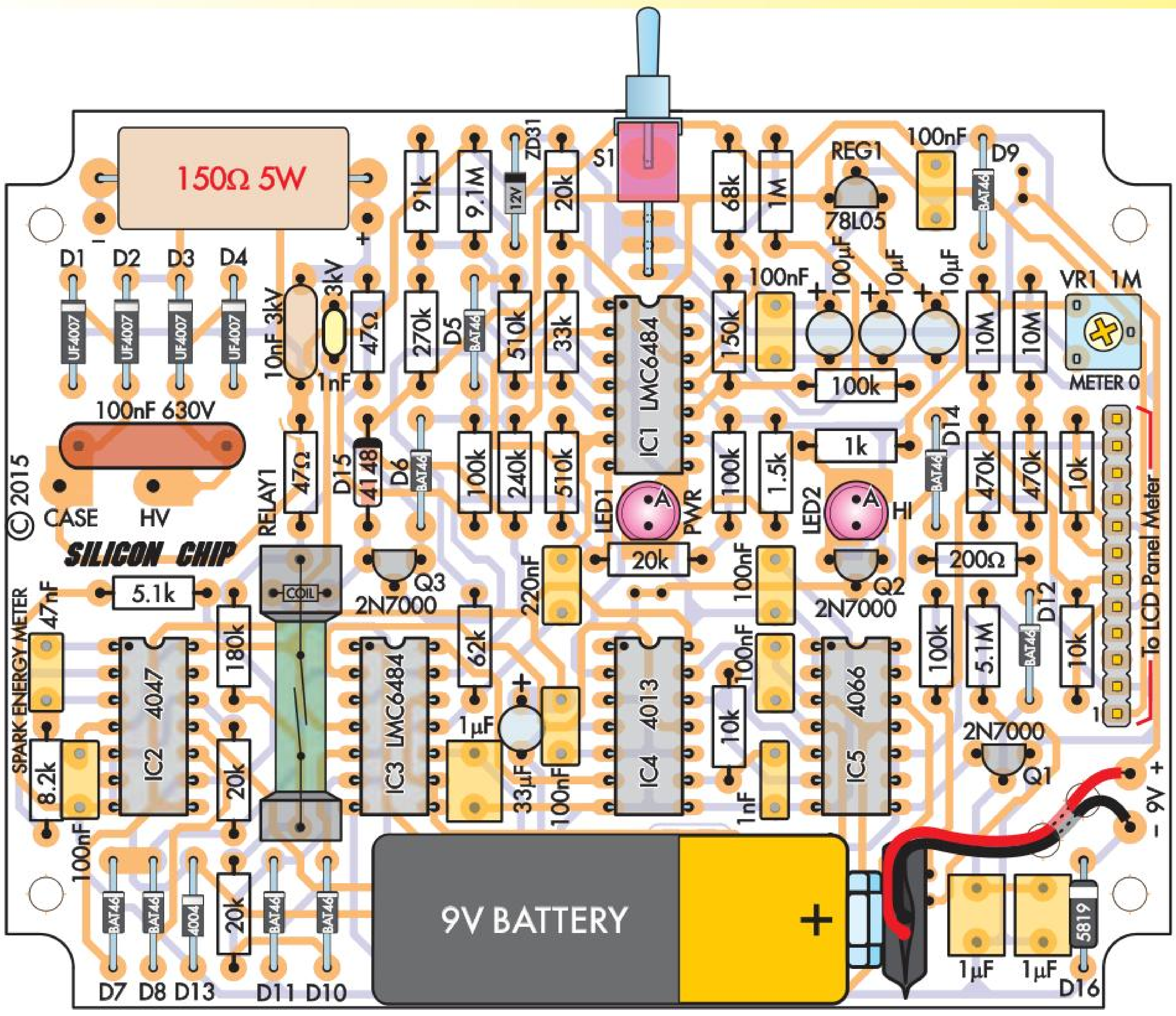
The 9-way rainbow cable is stripped into a 5-way length and a 4-way length. Separate out the wires for about 100mm on one end and strip off the insulation by about 1mm on this end of the cable.

Terminate to the LCD terminals and solder in place after a short length of heatshrink cable is placed over each wire. The heatshrink supports the wire to prevent breakage.

Note that the connection pins on the rear of the display are numbered from 1 to 13, but with pin 3 missing and left as a blank space. This separates the power at pins 1 and 2 from the remaining pins. Pin 4 is not used.

The other end is terminated into the header plugs and the metal contacts. These are designed to crimp the wires and then hold the wire and insulation using another set of bendable pieces on the terminal.

Use pliers to crimp these down. A small amount of solder applied to the crimped connector where the wire is


150Ω 5W
91k
9.1M
12V
ZD31
20k
S1
68k
1M
REG1
78L05
100nF
D9
D1 D2 D3 D4
UF4007
10nF 3kV
3kV
1nF
47Ω
270k
D5
510k
33k
IC1 LMC6484
150k
100µF
10µF
100k
10M
VR1 1M
METER 0
100nF 630V
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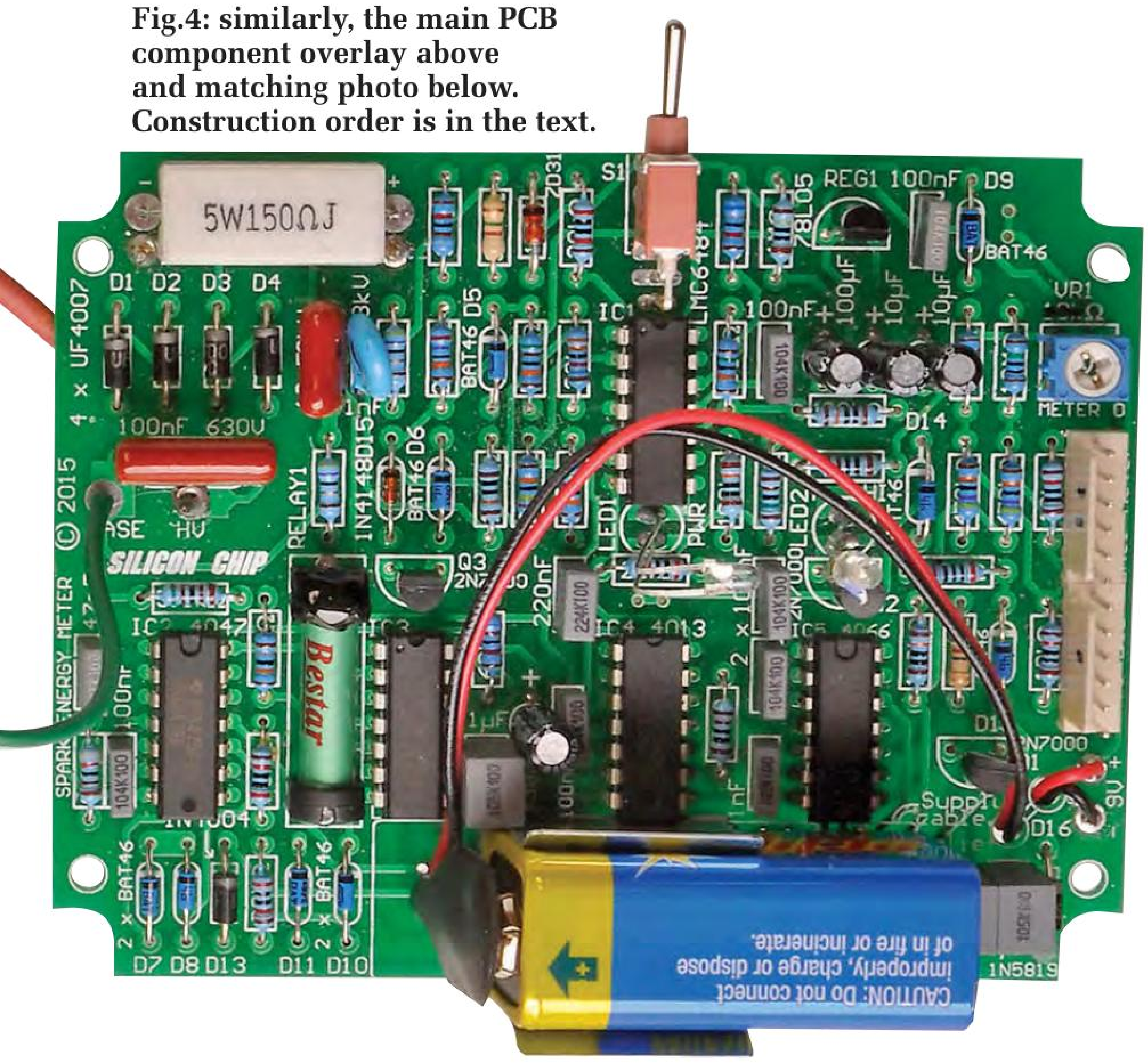
HV
SILICON CHIP
RELAY1
D15
4148
D6
240k
LED1
PWR
A
1.5k
1k
D14
470k
10k
LED2
HI
20k
200Ω
Q3
2N7000
220nF
Q2
D12
To LCD Panel Meter
5.1k
COIL
47nF
SPARK ENERGY METER
180k
IC3 LMC6484
62k
1µF
IC4 4013
IC5 4066
5.1M
IC2 4047
8.2k
33µF
1nF
Q1
9V
9V BATTERY
BAT46
4004
5819
D16
D7 D8 D13
D11 D10

Fig.4: similarly, the main PCB component overlay above and matching photo below. Construction order is in the text.



crimped will prevent the wire slipping out from the connector.

The crimp connectors are slid into their backing shells and pressed in using a small screwdriver till they click in place. Make sure the LCD module is wired correctly before applying power.

On power-up (when the 9V battery is connected or a separate supply), the power LED should show '.000' or close to it. VR1 can be adjusted to set the display to zero if needed.

If the display does not show these numbers, check wiring between the PCB and display.

Finally, make up a lead to connect to the spade connector on the case of the *Spark Energy Meter*. This comprises the remainder of the 1m mains wire with an alligator clip on one end and a crimp spade connector on the other. This is used to connect to mains earth when testing the spark from an ignition coil.

Accounting for the 150Ω wirewound resistor tolerance

Even though you normally set the *Calibrator* to give exactly 5V output, the reading on the *Spark Energy Meter* could be ±5% out due to the tolerance of the 150Ω, 5W wirewound resistor at the input (ie, it could be anywhere from 143Ω to 157Ω). Wirewound resistors are not known for their tight tolerance!

So your readings (which depend on this resistor) could also be out.

If you want it exact, the way around this is to measure the resistor and compensate. If you happen to measure exactly (or even very close to) 150Ω, you don't have to do anything. But if it's out, set the voltage from the *Calibrator* higher or lower than 5V by the ratio of your resistor to a perfect (150Ω) resistor.

For example, if your resistor measures 155Ω, set the voltage to 155/150 × 5, or 5.17V. Conversely, if it's lower, say 145Ω, set the calibrator output voltage to 145/150 x 5, or 4.83V.

If you need a suitable ignition coil driver then the *High Energy Ignition* from February and March 2014 includes a spark test feature where the coil is driven to check ignition operation.

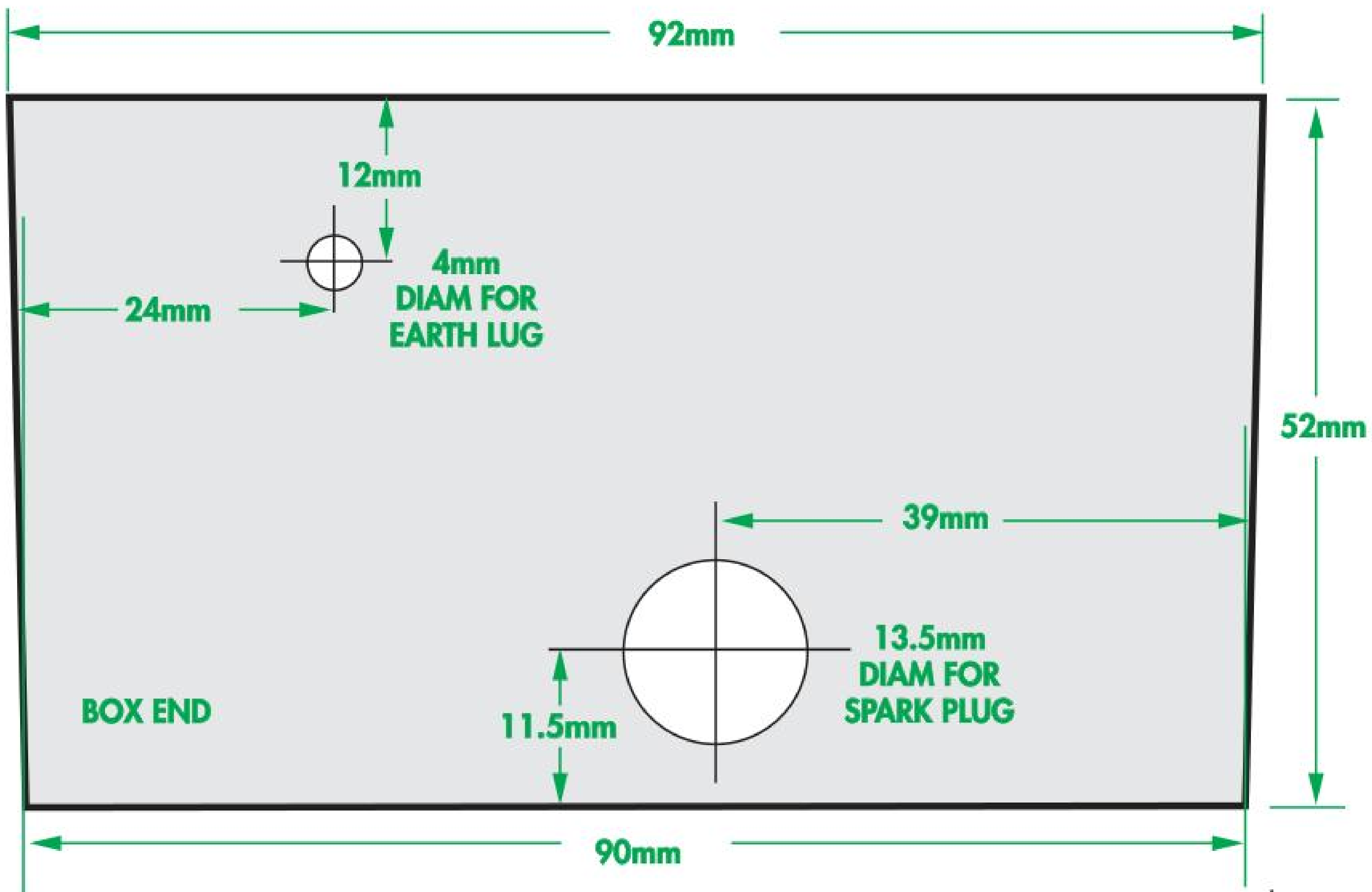
Calibrator construction

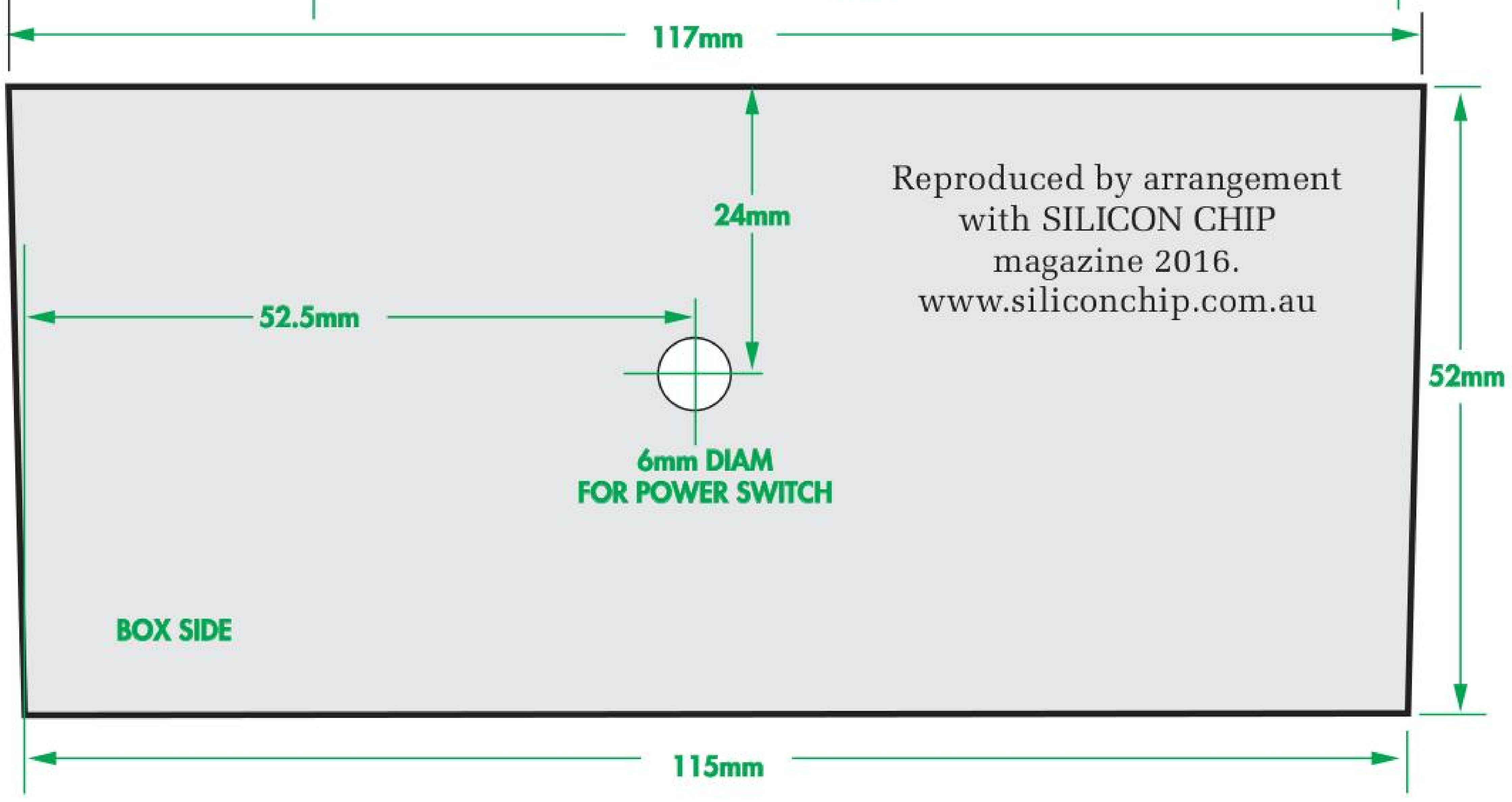
The *Spark Energy Meter Calibrator* is constructed using a PCB, available from the *EPE PCB Service*, coded 05101153 and measuring 47 × 61mm. The PCB will clip into the side pillars in a standard UB5 utility box (83 × 54 × 31mm) although we present this as a bare PCB. Note that there are two versions, the calibrator and the PWM driver, so follow the overlay diagram for the version you are building.

The PWM circuit will produce an approximately 500Hz waveform. Depending on your application, this may be too high. For a small DC motor for example, a 100Hz drive may be more suitable. The 10nF capacitor can be changed. Use a 47nF one for a nominal 100Hz PWM drive.

Follow Fig.6 for the PCB assembly. Install the resistors first. (A digital multimeter should be used to check/confirm their values.) Note that for the calibrator, a wire link is required

Fig.5: drilling detail for the end of the *Spark Energy Meter* diecast case (at right) and the side of the same case (below). See pic and note at right re spark plug tapping.


92mm
12mm
24mm
4mm DIAM FOR EARTH LUG
52mm
39mm
13.5mm DIAM FOR SPARK PLUG
BOX END
11.5mm
90mm


117mm
24mm
52.5mm
52mm
6mm DIAM FOR POWER SWITCH
BOX SIDE
115mm

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Drill and ream the spark plug hole through the end of the case to a size *just* smaller than the plug thread, then use the plug thread itself to 'tap' the softer aluminium. This will make the spark plug captive.

between VR1 and VR2. This wire link is replaced with a 1N4148 diode if the alternative circuit is built.

Diodes are next and these need to be installed with the correct polarity with the striped end oriented as shown in the overlay diagram.

Install the IC now, noting the correct orientation for pin 1. REG1 and Q1 can then be installed. These lie horizontally on the PCB after the leads are bent over by 90 degrees to fit into the mounting holes. The metal tabs can be held against the PCB using M3 × 10 screws and M3 nuts if required.

Q2 and Q3 are mounted next, taking care not to transpose them. The capacitors can be installed next; the electrolytic types with the polarity shown. Install the three PC stakes, along with the trimpots and the two 2-way screw terminals. These are oriented with the wire entry toward the outside of the PCB.

Testing and setting up

Apply a 7-12V supply to the input screw terminals. Connect a multimeter to the 0V and 5V PC stakes and adjust VR1 for a reading of 5.0V. The second adjustment requires access to a frequency meter. Many multimeters now include frequency metering and will be suitable for the 250Hz setting.

Alternatively, an oscilloscope can be used. Using test point TP1 and the 0V PC stake as the common connection, adjust VR2 for 250Hz. On an oscilloscope this will be a square wave with a 2ms high level duration and a 2ms low duration.

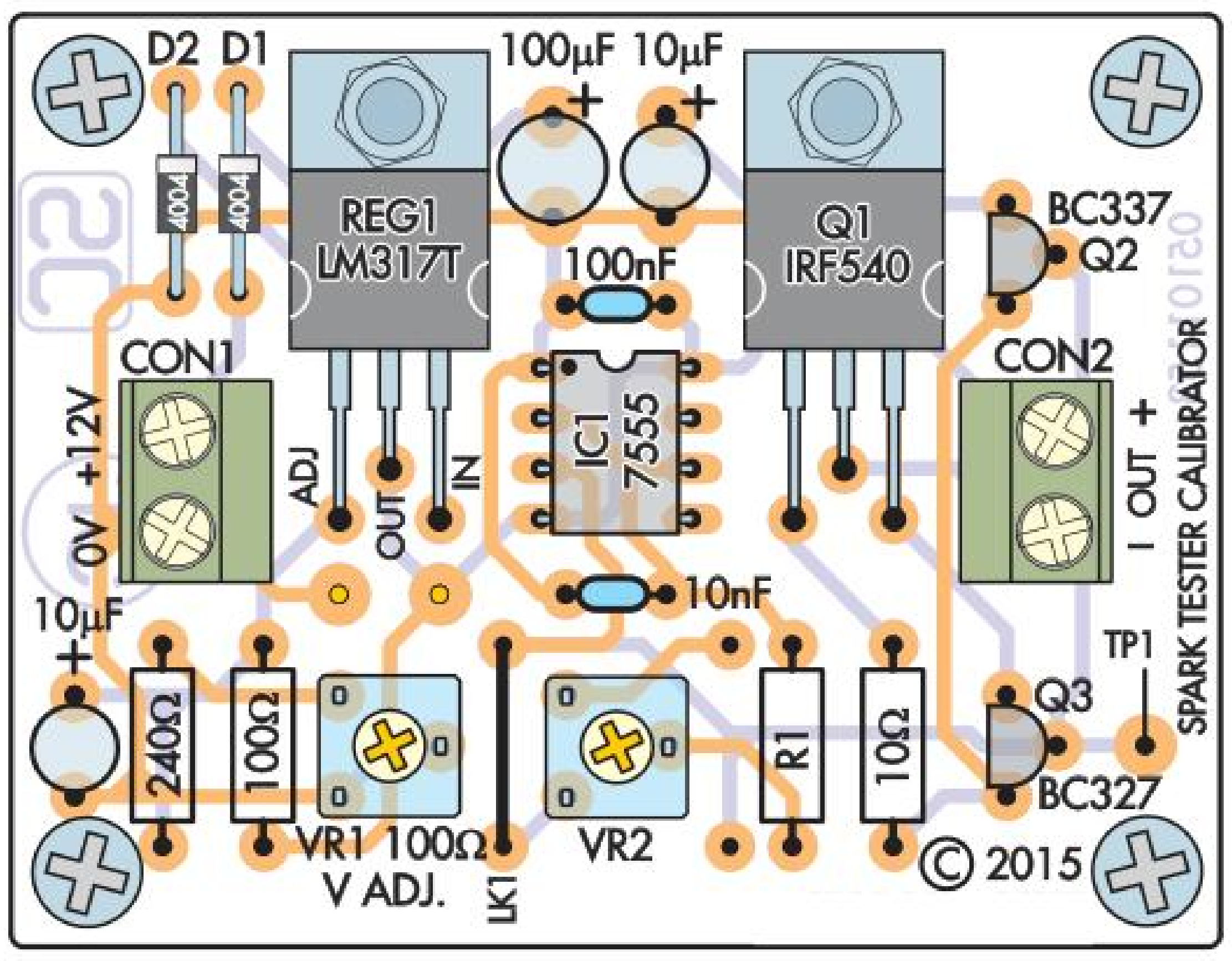
For calibration of the *Spark Energy Meter*, the plus (+) terminal on CON2 of the *Calibrator* connects to the plus (+) PC stake on the *Spark Energy Meter*. Similarly, the minus (–) terminal on CON2 of the *Calibrator* connects to the minus (–) PC stake on the *Spark Energy Meter*.

Make sure the *Calibrator* is powered by a different supply to the *Spark Energy Meter* and that at least one supply is floating with respect to earth (ie use a battery for one supply). Switch on the *Spark Energy Meter* and *Calibrator* and adjust the trimpot within the LCD module for a reading of 100mJ.

Using it

There are two ways to use the meter. First, the meter's ground

Fig.6: the *Calibrator* PCB component overlay and an enlarged photo (for clarity) alongside. Trimport VR1 adjusts for exactly 5V output (or calculated output to account for wire-wound resistor tolerance – see text). VR2 adjusts for the correct frequency at 250Hz.


D2 D1
4004
4004
REG1 LM317T
100µF 10µF
Q1 IRF540
BC337 Q2
100nF
CON1
CON2
0V +12V
ADJ
OUT
IN
IC1 7555
– OUT +
SPARK TESTER CALIBRATOR
10µF
10nF
TP1
Q3
BC327
240Ω
100Ω
R1
10Ω
VR1 100Ω
V ADJ.
VR2
LK1
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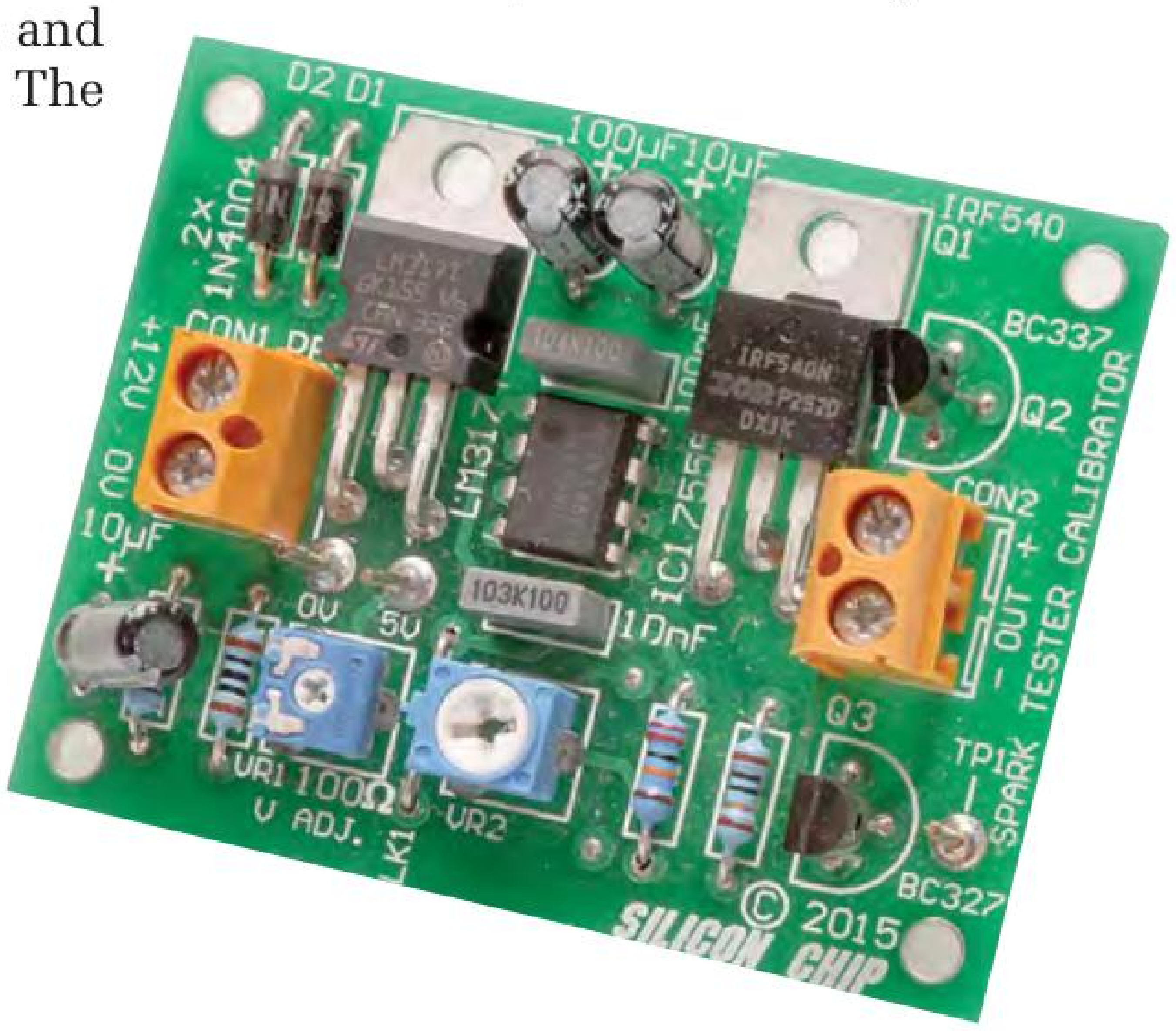

SILICON CHIP
SPARK TESTER CALIBRATOR
© 2015

connection is clipped onto a secure ground point to avoid the meter body developing a high voltage potential during the spark.

The spark plug wire can be lifted from one of the engine's spark plugs and plugged onto the meter spark plug input. Then, with the engine running (which will have a miss as one spark plug is not operational), the meter reads that spark energy in milliJoules (mJ). This can be done for all the engine's spark plug feeds for comparison, one at a time.

In a 4-cylinder car, the frequency of the sparks presented to a single plug by the distributor is about 4Hz when the idle rate is 500 RPM.

Some cars, which have an individual ignition coil per spark plug with custom assemblies can also be measured if an appropriate connector system is made to access the high voltage terminal where the spark is normally generated and using a non-powered dummy coil/plug module to re-seal the combustion chamber.

The second way to use the meter is to disconnect the ignition coil from the distributor and measure its output directly while cranking the engine (naturally, the engine will not start).

This will give a higher energy reading as it bypasses the losses in the distributor's spark gap and the differences in these measurements will give an indication of the distributor's spark losses.

In systems with wasted spark or two terminal ignition coils, as in Commodore and many General Motors engines, one of the ignition coil outputs is shorted to ground and the other terminal is measured by the meter.

Use as a low-voltage speed control or dimmer

The *Calibrator* circuit published in last month's issue included an alternative *PWM Drive Circuit* (shown in a yellow panel). This modification can then make this board usable as a 12V DC motor speed control or even a 12V incandescent/LED light dimmer.

See the revised component overlay below. There is a link (LK1) and a pair of unused pads alongside VR2. Replace this link with a 1N4148 diode (anode towards the PCB edge) and another 1N4148 across the unused pads (same orientation). Two other changes are needed: VR2 is changed from a 50kΩ to 250kΩ (or it could be replaced with an external pot if that's more convenient) and R1 is reduced from 220kΩ to 1kΩ .

A 12V motor or lamp needs to be run from the incoming 12V supply (at CON1), not the '+' output terminal on CON2, which is at 5V. You take +12V DC from the CON1 '+' input terminal and connect the 0V to the CON2 '–' output terminal, as shown below.

Obviously, if you have a 5V motor or lamp, you can use both 'normal' output terminals, CON2.

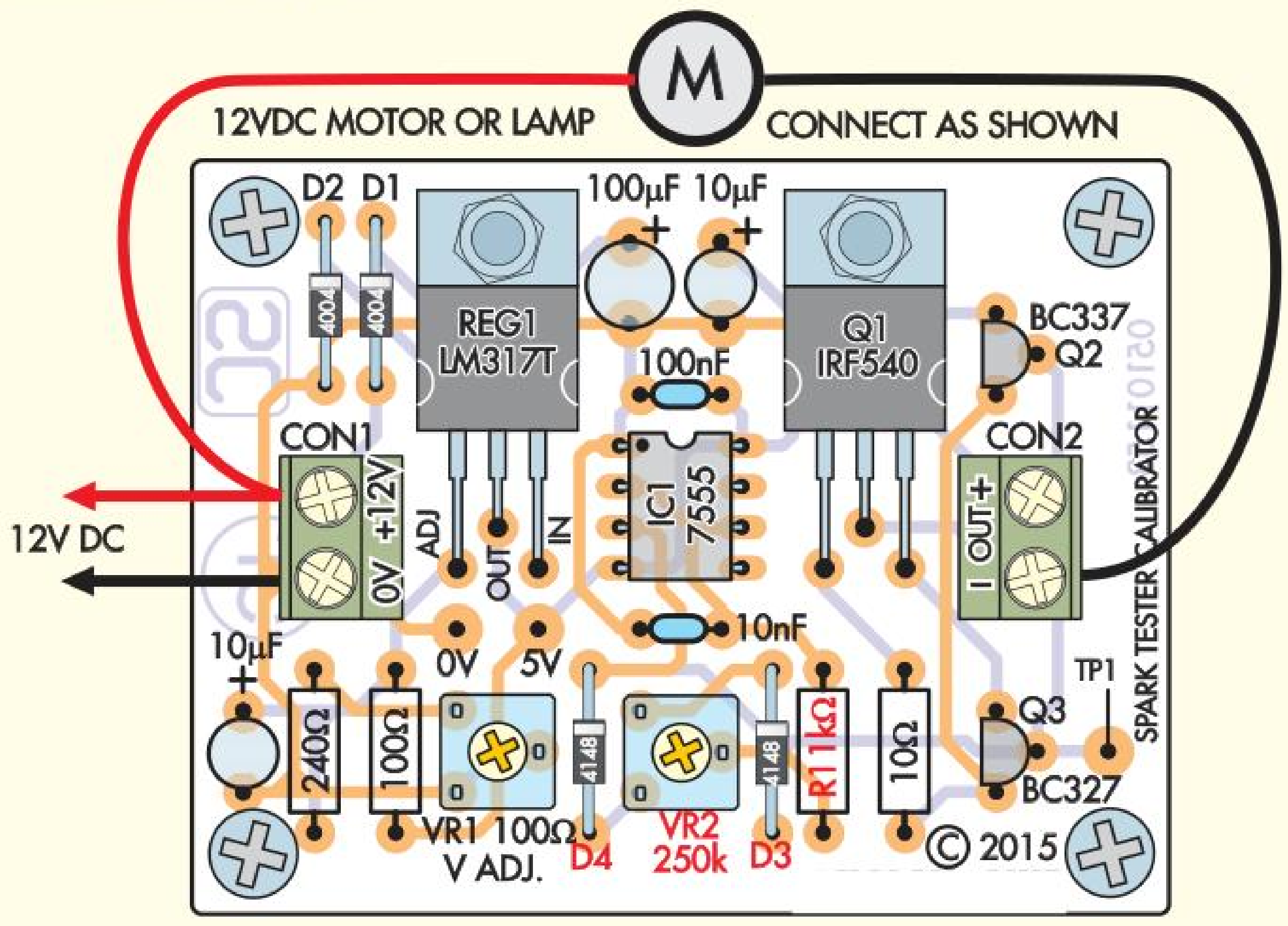
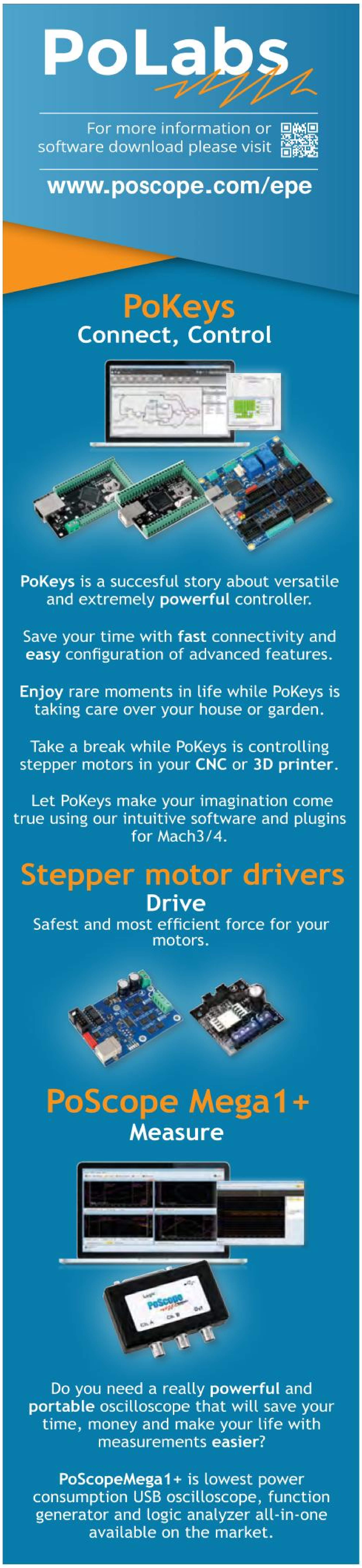


Fig.7: the changes (shown in RED) required to turn the calibrator circuit into a 5V or 12V motor speed controller or incandescent/LED lamp dimmer. At 12V, connected as shown above, it will deliver up to 5A if the 12V supply is capable of that current. At 5V, the limit would be 1A, the maximum current allowed through D1 and D2. (The LM317T can deliver around 1.5A).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Modifying the Currawong Valve Amplifier

. . . is it worthwhile?

By Allan Linton-Smith and Leo Simpson

While the *Currawong Valve Amplifier* has created a great deal of interest, some readers would like to see it with improved frequency response, better output transformers, more expensive valves and so on. We have investigated a number of these possibilities and you can judge for yourself whether all or any of the modifications discussed are worthwhile.

MOST READERS would regard the output transformers we used as looking physically puny compared to the much larger transformers fitted to valve amplifiers in the 'olden days' and we would have to agree. So could bigger and better output transformers improve the performance? Possibly.

Before we had a look at that topic we had to address a query about the low-frequency response of the *Currawong*. As depicted in the graph of Fig.5 in the November 2015 issue, the frequency response had a slight upturn at around 20Hz. Some people blamed this on the relatively small 100µF capacitors at the cathodes of the 6L6 output valves.

The Hashimoto HW-40-5 is much larger, heavier and more expensive than the Altronics M1115 line transformer. While its frequency response is flatter above 3W, the M1115 actually provides substantially lower distortion over most of its frequency range. This is likely due to its use of grain-orientated steel in the core

These supposedly did not allow sufficient decoupling at the lowest frequencies and the gain climbed slightly as a result. We did not agree with this contention for the following reason: increasing the cathode bypass capacitors will actually increase the low frequency open-loop gain, but the effect of negative feedback will be to negate this anyway, and it will therefore have negligible effect.

Thus, we ran the frequency response test with an 8Ω load again and compared the response with 100µF and 200µF capacitors (ie, with another 100µF in parallel) bypassing the 330Ω cathode resistors. Fig.1 shows the results and as expected, there is negligible difference in the two curves.

By the way, these curves are even flatter than those originally published in the November 2015 issue and we can only put this down to a slightly different valve line-up and wiring layout in the final prototype of the amplifier. We should also point out that, as in any

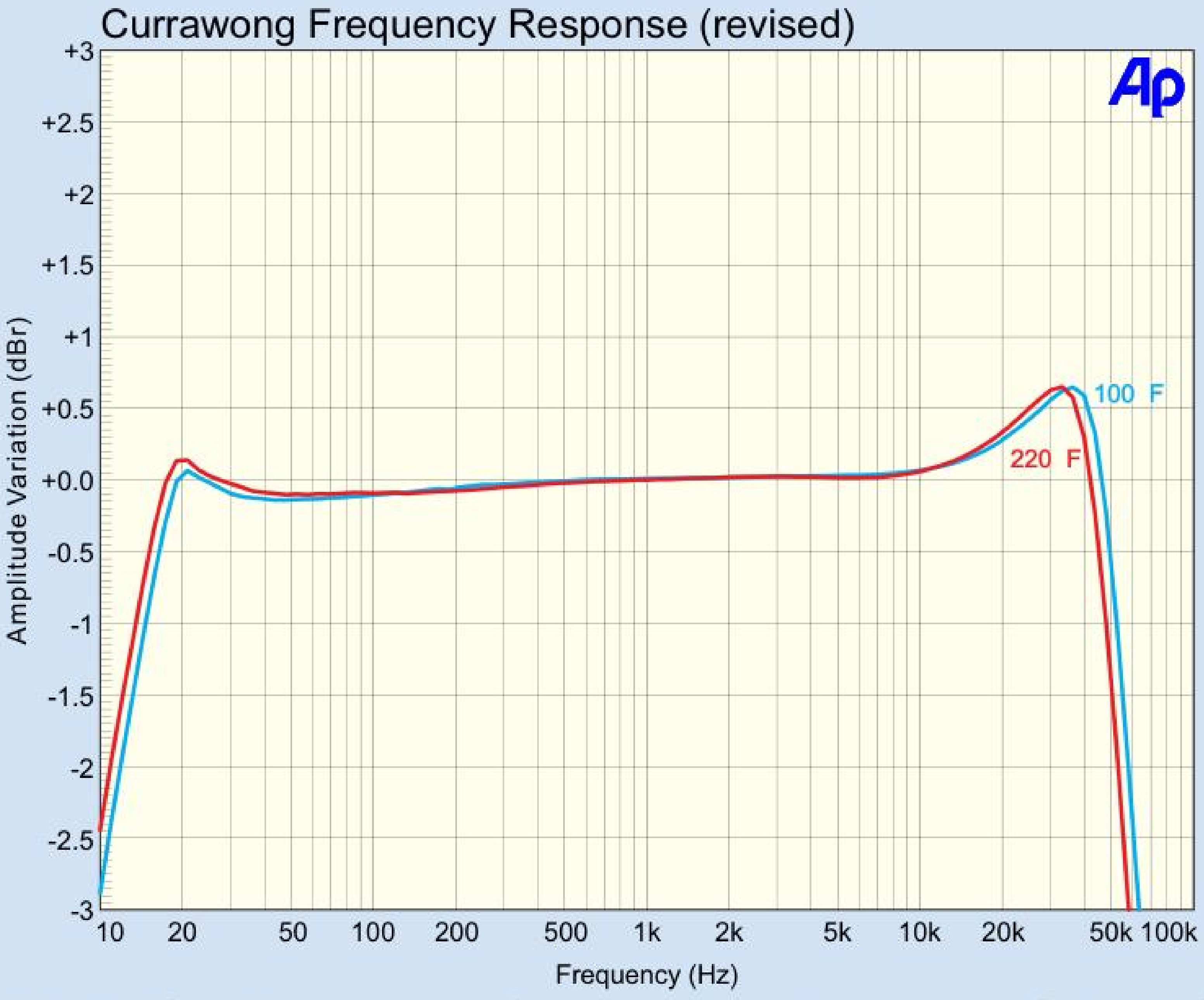

Fig.1: the Currawong frequency response as designed (blue) and with extra output stage cathode resistor bypass capacitance (red).

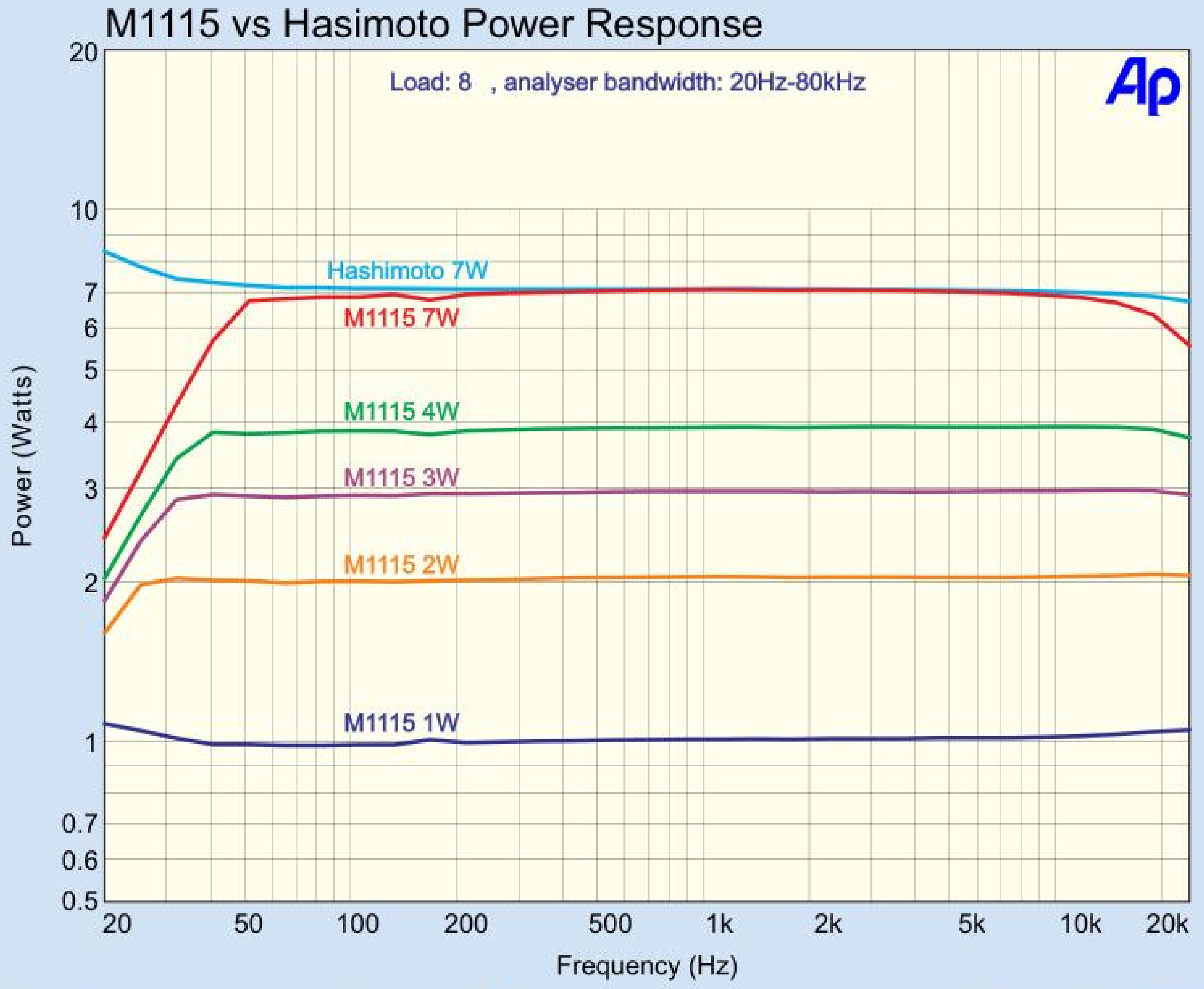

Fig.2: a comparison of the power response of the M1115 and Hashimoto transformers in the Currawong at various power levels.

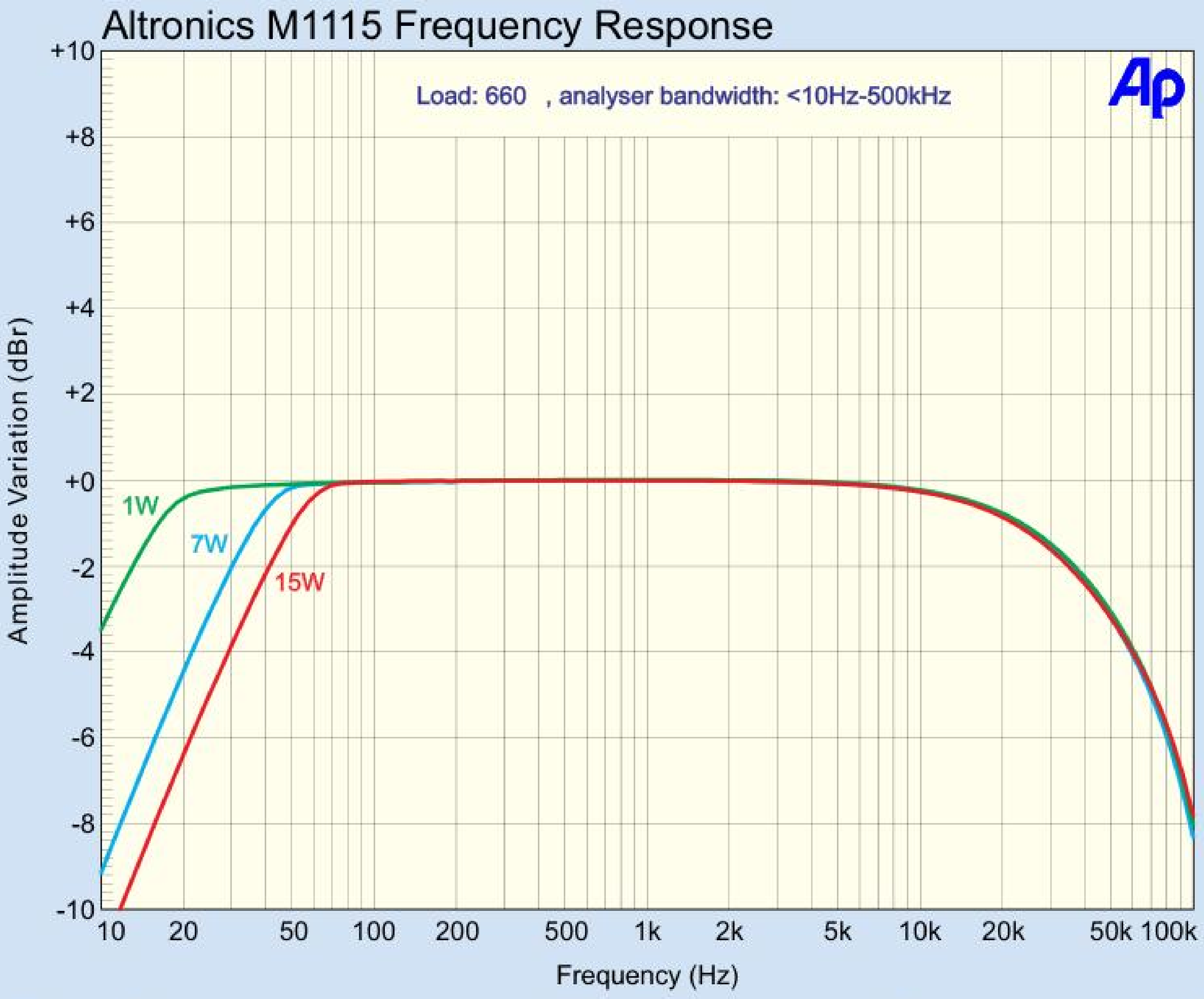

Fig.3: frequency response of the M1115 transformer operated open loop into a 660Ω resistive load. The load resistance gives 15W at its design output voltage of 100V.

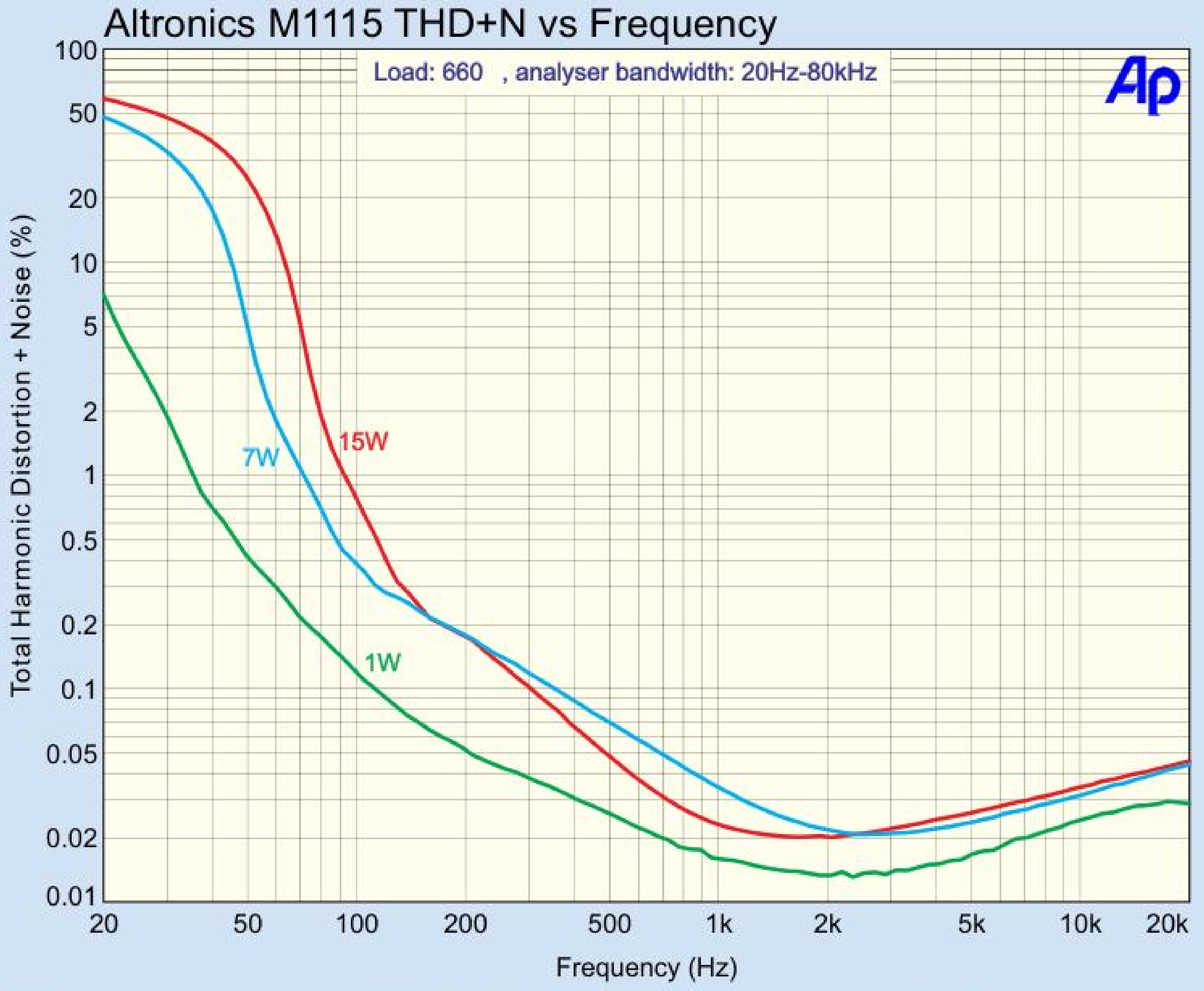

Fig.4: distortion of the M1115 transformer with the same set-up as in Fig.3. The distortion is quite low at 1W but increases at higher power levels and lower frequencies.

typical high-performance valve amplifier, the *Currawong* needs to run for at least half an hour before it produces the best performance.

Now to the question of the output transformer. A number of readers have pointed out that we should have published power response curves for the *Currawong*, as these would soon throw up the deficiencies of the Altronics line transformer.

Hence we have prepared a series of power response curves and compared these to a highly regarded substitute transformer, the Hashimoto HW-40-5, made by Hashimoto Electric Ltd in Tokyo, Japan (available at more than US$700 for a pair). The frequency response claimed by the manufacturer is flat from 10Hz-60kHz ±0.1dB and it has an input impedance matched specifically for 6L6 valves of 5kΩ and output taps at 4Ω, 8Ω and 16Ω. It is suitable for amplifier powers up to 40W.

These transformers weigh 2.4kg each and are far too big and heavy to be mounted on the *Currawong* PCB, so they were externally mounted with longer leads.

Fig.2 shows a number of power response curves run with the Altronics transformer and one with the Hashimoto transformer at an output power of 7W into an 8Ω load. Looking at the curves, the Altronics transformer does lack bass power at higher levels, but is quite adequate up to about 3W RMS, whereas the Hashimoto transformer has a flat power response down to below 20Hz.

The Hashimoto transformer was also tested for frequency response at various power levels up to 20W without negative feedback. Under this condition, the Hashimoto performs much better than the Altronics unit, as would be expected. Given that result, you might expect that the Hashimoto would produce significantly less harmonic distortion when feedback is applied (as in the normal *Currawong*

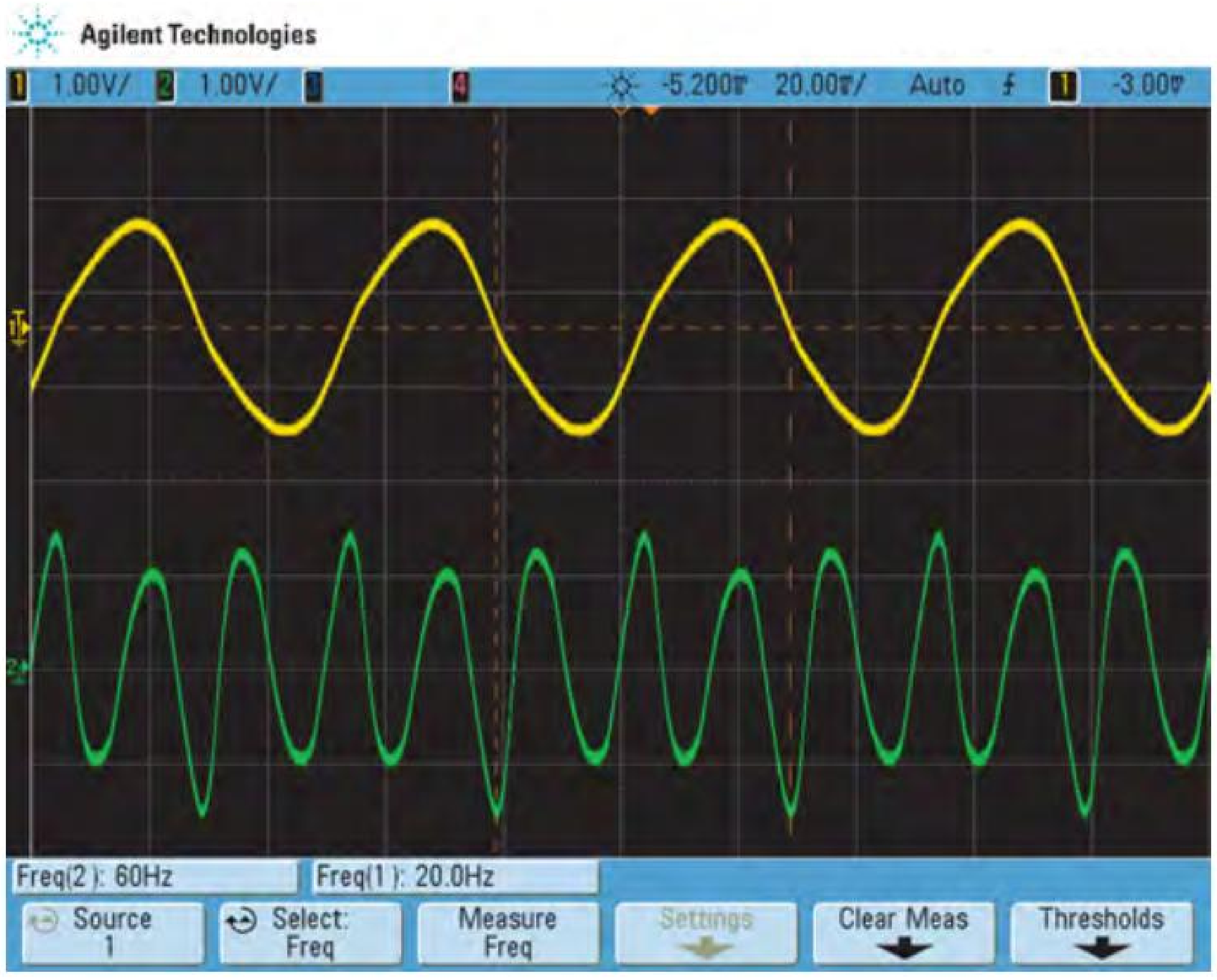

Fig.5: distortion from the Currawong with M1115 output transformers driving an 8Ω load at 20Hz and 1W. The residual is largely third harmonic and while the waveform distortion is clearly visible, it's still somewhat sinusoidal.

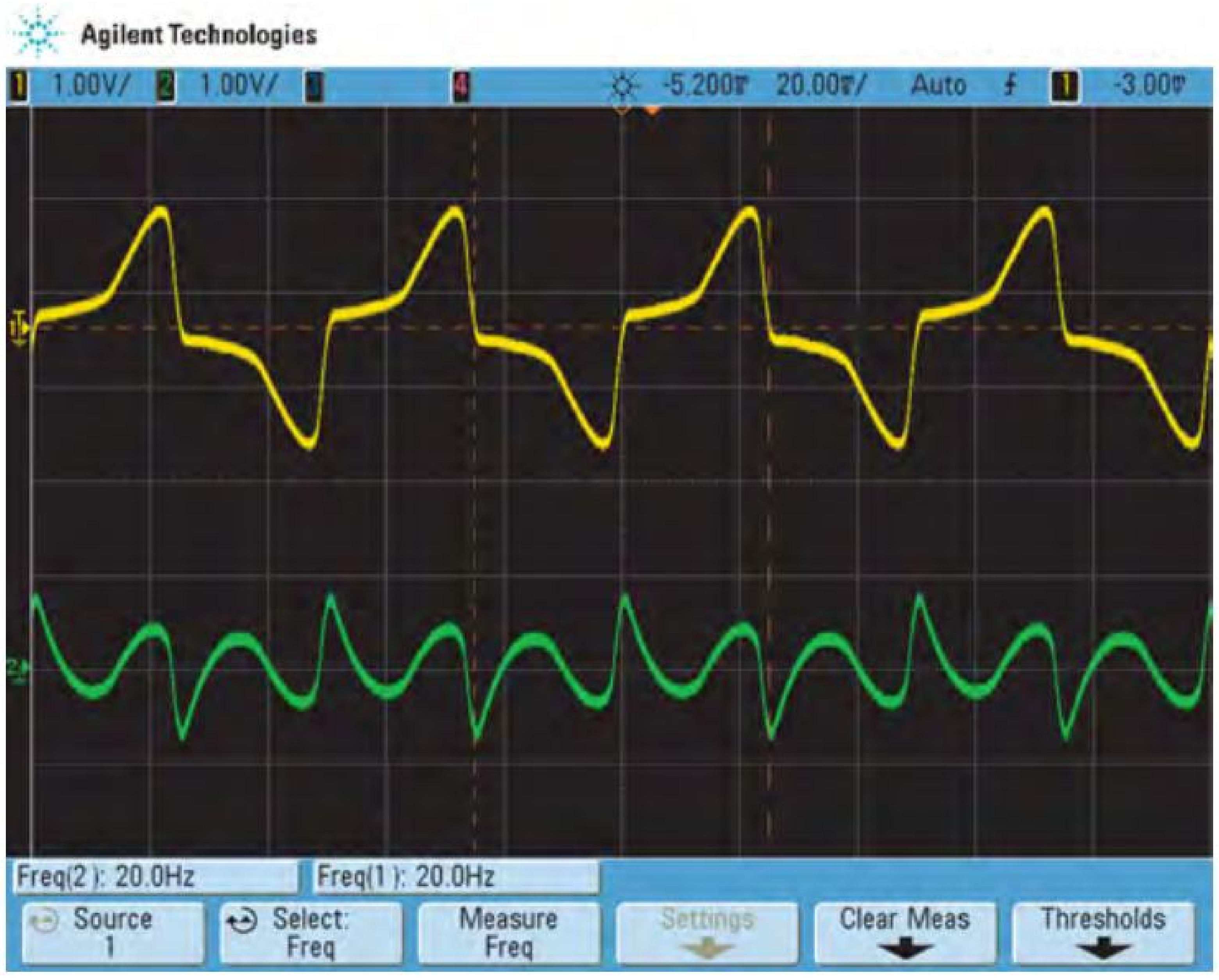

Fig.6: same as for Fig.6 but at 4W. It certainly doesn't look like a sinewave any more! The global feedback is applying maximum bias to try to correct the waveform but the transformer is saturated and it simply isn't possible.

configuration) but surprise, surprise, it turned out that the THD+N at 1W was higher than the cheaper transformer, as shown in Fig.7.

The negative feedback in the *Currawong* circuit is quite high for a valve amplifier and this will linearise the response and reduce harmonic distortion in the smaller transformer. Hence, the negative feedback was reduced to zero to see if the Hashimoto could do with less and therefore produce more power. It did and the best we could squeeze out of it was 20W, but the harmonic distortion was a whopping 20% at 1kHz (with zero feedback).

Subjective listening tests

Subjective listening tests proved that the Hashimoto is a very good transformer but at more than 40 times the price of the Altronics M1115, it really is only marginally better. Of course, both transformers could deliver more power if the *Currawong* amplifier was run with much higher power supply rails and the circuit bias modified to suit.

However, the cheaper transformer would still be deficient in power response at the low frequency end, simply because its core is not big enough. To illustrate just how good (or bad, depending on your viewpoint), we decided to do a number of tests on the Altronics M1115 transformer when driven by a high-quality solid-state amplifier. In this case, the amplifier was connected to the primary winding and the transformer was used in step-up mode, as a 100V line transformer.

The secondary winding was loaded with a 660Ω 15W resistor (three 220Ω 5W resistors in series). In this mode, the transformer delivers 15W.

Fig.3 shows its frequency response at power levels of 1W, 7W and 15W. As can be seen, it's pretty good at 1W and obviously somewhat deficient at the low-frequency end when driven at 7W or 15W. This is due to core saturation.

The equivalent THD+N curves in Fig.4 reinforce the story and you can see that harmonic distortion rises drastically at the lower frequencies and particularly at high power levels.

To further demonstrate how transformer core saturation affects the low-frequency response, have a look at the scope grabs of Fig.5 and Fig.6. Fig.5 shows a 20Hz signal at 1W with the upper (yellow) trace being the transformer output while the lower (green) trace is the harmonic distortion; predominantly third harmonic at 60Hz.

Fig.6 is significantly worse with a 20Hz signal at 7W. Here the output of the transformer is running well into saturation and the harmonic distortion waveform is quite a bit worse, with more higher-order harmonics. At higher power levels, the story is similar with the distortion climbing to over 60%, as can be seen from Fig.4.

Now let's consider the low-frequency power response and harmonic distortion of the *Currawong Amplifier*. This demonstrates the miracle of negative feedback. Without negative feedback applied in the *Currawong Amplifier* circuit, the performance is pretty awful and even with the Hashimoto transformer, it is pretty ordinary. Negative feedback makes all the difference in the *Currawong*, as it does in any other high-performance valve amplifier.

Next time you read how valve amplifiers can sound good without negative feedback, you will know that the writers are simply ignorant!

Various valves

A quick search of the internet will glean a lot of information, opinions and prices for various valve brands, ages and types. You will also see how many valve aficionados prefer 'NOS' valves (New Old Stock) which have been manufactured up to 50 years ago but have never been used (and sometimes in the original box). If you go to **www.tubedepot.com** you will find more than 30 different types of 12AX7 priced from US$11.95 for a basic Electro-Harmonix right up to US$540.95 for a 'Black Sable Mullard'.

You may well wonder how much improvement you might get from the higher-priced valves. We would advise extreme caution. NOS valves can command high prices but it is very much a case of 'buyer beware'. Such valves may have been used (definitely not 'new'!) and there are even forgeries of the most popular types.

If you have built the *Currawong* and then start swapping valves you may notice differences between similarly priced valves such as Electro-Harmonix (from Altronics) versus Sovtek (from Jaycar). But while these differences may be discernible and you might like one or the other depending

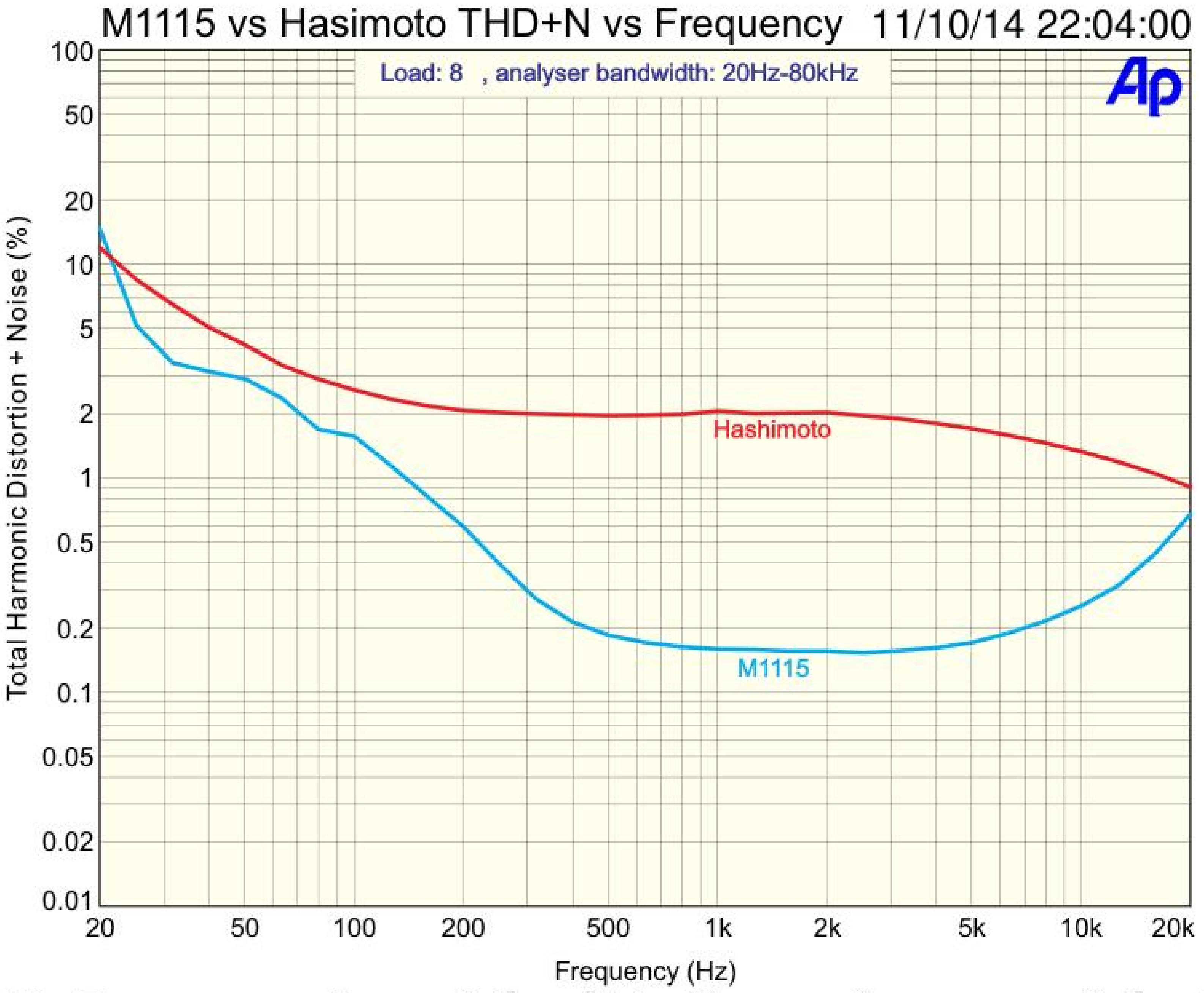

Fig.7: a comparison of the distortion performance of the M-1115 and Hashimoto transformers at 1W without negative feedback. Surprisingly, the M1115 has much lower distortion.

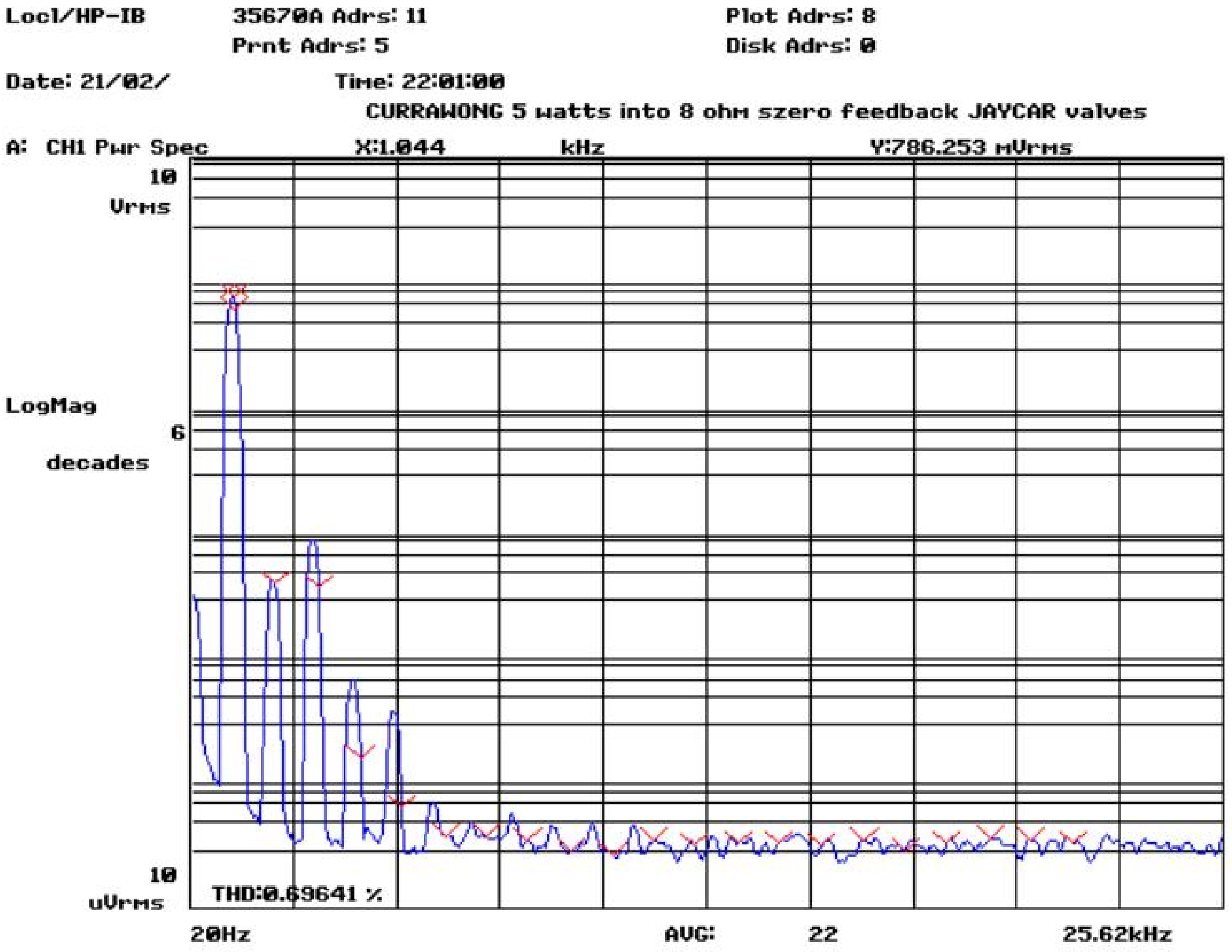

Fig.8: spectral response for the Currawong at 5W into an 8Ω load using the Jaycar-supplied Sovtek 12AX7 valves. The result is slightly different to that achieved when substituting valves from other manufacturers.

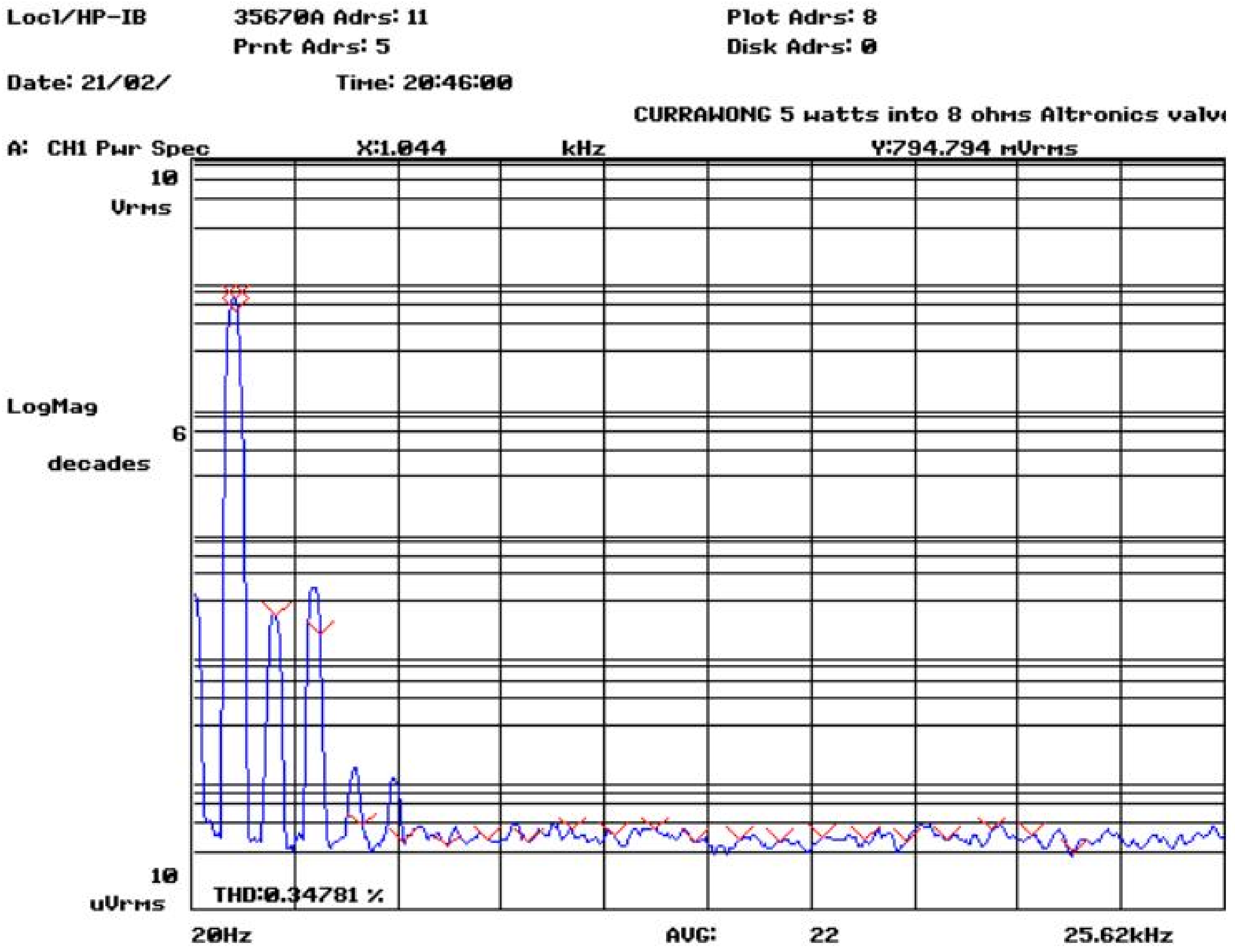

Fig.9: spectral response for the Currawong under the same conditions as Fig.8 but using Electro-Harmonix 12AX7 valves supplied by Altronics.

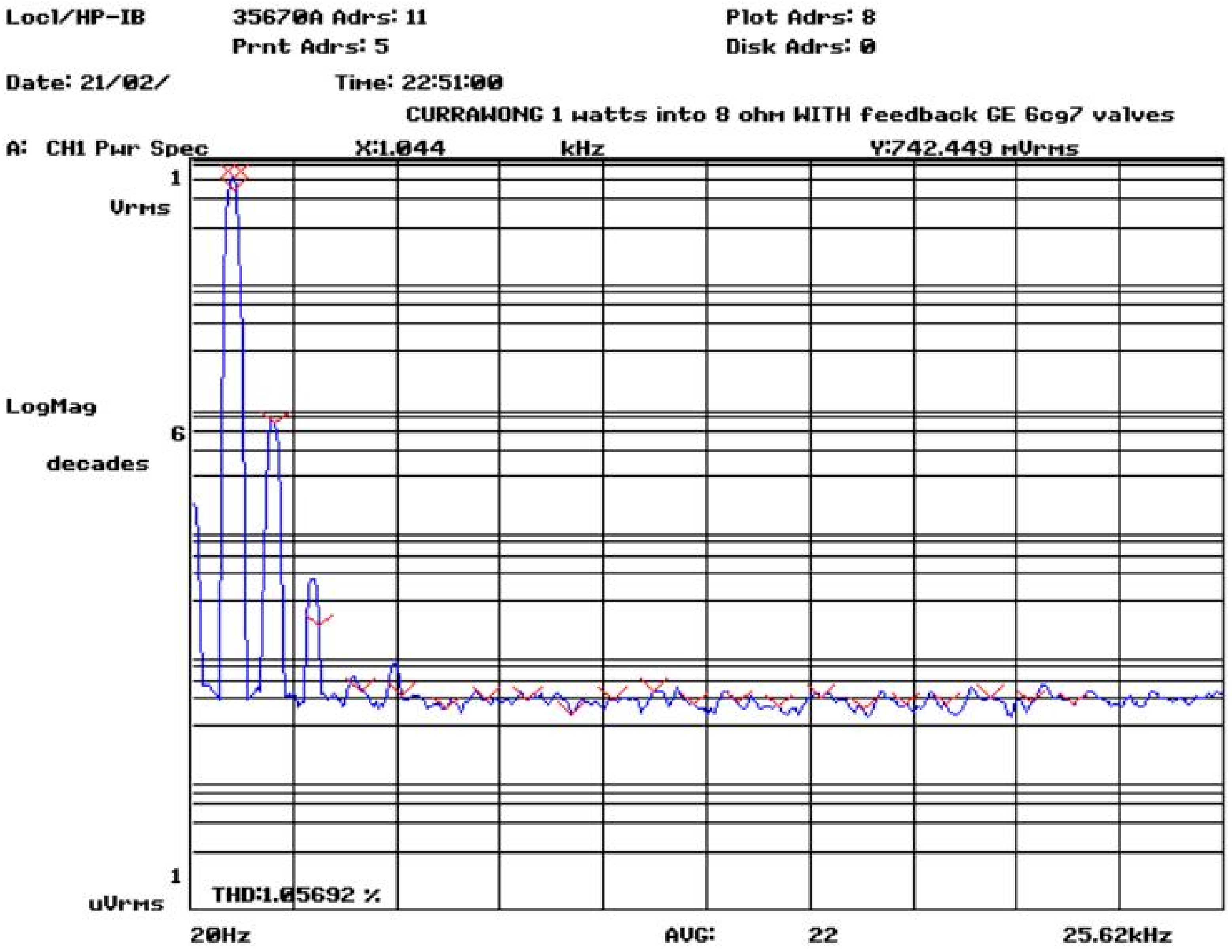

Fig.10: spectral response for the Currawong at 1W using 6CG7 valves but with feedback enabled. Note that these valves require a 6.3V filament supply.

on the type of music you prefer, objective tests will show that frequency response and total harmonic distortion are quite similar.

With that in mind, you might discount subjective differences. But it turns out that the differences are real and hence perceptible, which is backed up by the different spectra for these valves. You can see the results in Fig.8 and Fig.9. In both cases, the input signal is a 1kHz sinewave and spectra show the amplitudes of the various harmonics.

Apart from the multiple different brands of 12AX7 and 6L6 valves, you could also try 6CG7s in place of the 12AX7s but then you will need to run the filaments at 6.3V AC, not 12V AC. The 6CG7 is a very linear valve previously used in TVs for vertical oscillators to maintain a non-distorted picture. These valves are now available at Altronics.

The spectrum for the 6CG7 is shown in Fig.10. Note, though, that this was plotted at a 1W power level and with feedback enabled, in contrast to Figs.8 and 9. So use caution when comparing these results.

There is also the possibility for using KT66 valves in place of the 6L6s. These are significantly bigger and bulkier which does look more impressive. The performance is again very similar but they are more expensive. The *Currawong* PCB is designed to accommodate them.

Conclusion

We hope that readers now understand that the Altronics M1115 transformer really does deliver quite a respectable performance in the *Currawong* and especially so, given its low price.

Yes, we could have selected much more expensive transformers, but the major increase in cost would simply not be justified in view of the small difference in performance. However, swapping valves to find which ones you prefer is worthwhile and a lot of fun.

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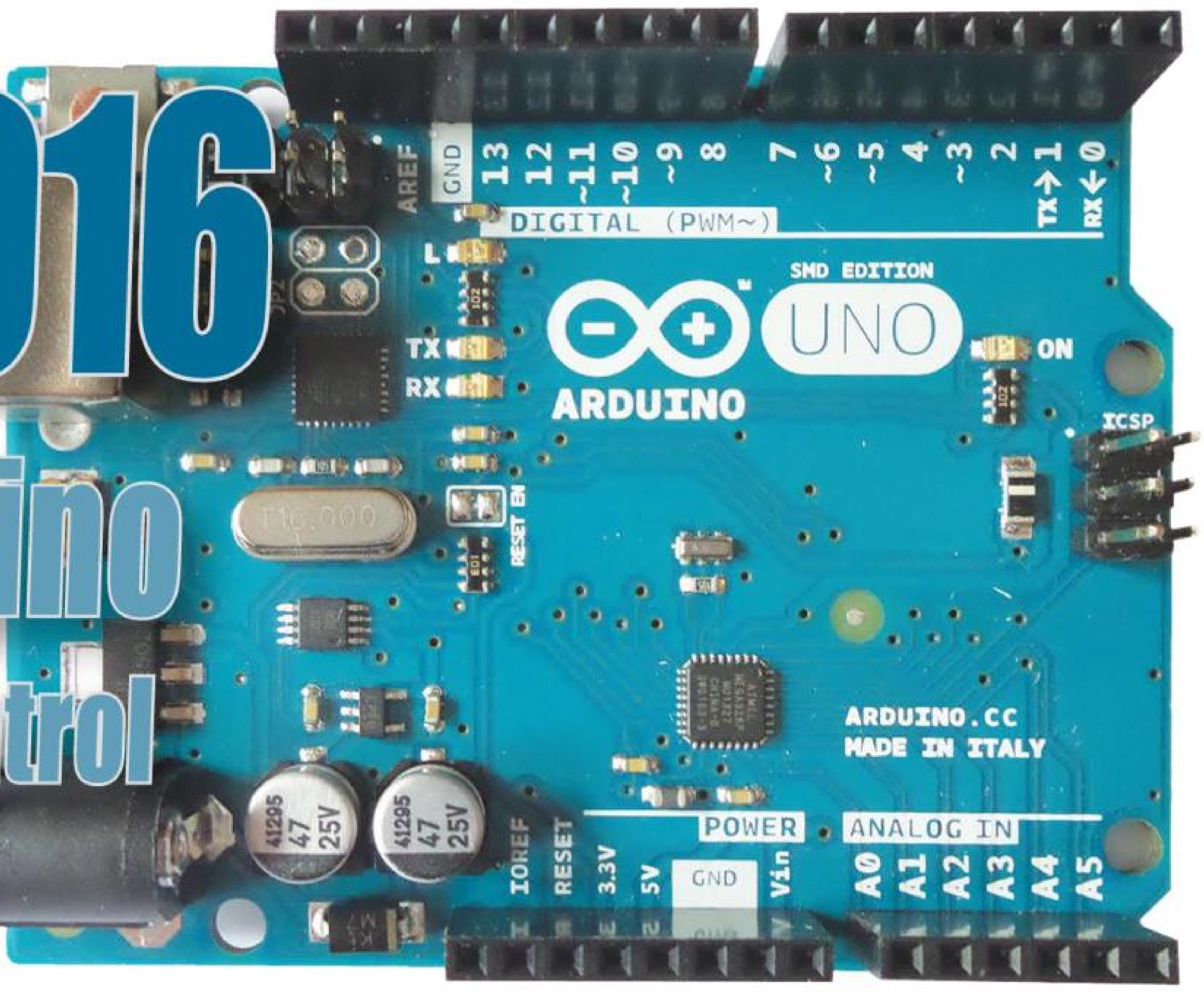
Teach-In 2016

Exploring the Arduino

Part 2: Relay and switch control


AREF
GND
13
12
~11
~10
~9
8
7
~6
~5
4
~3
2
TX→1
RX←0
DIGITAL (PWM~)
L
TX
RX
SMD EDITION
UNO
ON
ARDUINO
ICSP
ARDUINO.CC
MADE IN ITALY
POWER
ANALOG IN
IOREF
RESET
3.3V
5V
GND
Vin
A0
A1
A2
A3
A4
A5

by Mike and Richard Tooley

Welcome to *Teach-In 2016 – Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

In last month's *Teach-In 2016* we took a first look at the Arduino, explaining why this particular microcontroller has become so popular. *Arduino Workshop* dealt with installing and running the Arduino's simple but powerful integrated development environment (IDE) while *Coding Quickstart* introduced the different types of data that you will encounter in an Arduino environment. *Get Real* examined interfacing switches and LEDs to the Arduino's digital I/O ports and provided you with some simple example 'sketches' to get you started with C coding. For good measure, we introduced UnoArduSim, an easy-to-use, but very useful Arduino simulator that will allow you to develop and test your code without needing to have a real Arduino to hand.

This month

In this month's *Teach-In 2016* we will look at methods of connecting real world hardware to the Arduino Uno. To this end, *Arduino Workshop* deals with driving external loads while *Arduino World* looks at some handy low-cost interface boards that will allow you to drive high-current and high-voltage loads, such as mains operated lamps and motors. *Coding Quickstart*, our regular programming feature, explains the structure and layout of program code as well as introducing decisions and how to make them. Finally, *Get Real* will show you how to design and construct a simple but effective Arduino-based security system.

Arduino Workshop: Driving external loads

Last month, we mentioned that the ATmega328 processor provides a total of 23 input/output (I/O) lines. These lines are made available at one or more of the Uno's I/O connectors (see Fig.2.1). We explained that the I/O pins can be given different functions depending on the software configuration. The I/O port lines can be individually configured as inputs or outputs using the `pinMode()` function to configure the port direction (ie, input or output) and `digitalWrite()` to turn the respective line on or off. Note that the action is latching, so that, once an output is turned on or off it will remain in that state until a further command is generated to change the state.

Relay outputs

The Arduino's I/O pins can source or sink a maximum current of 40mA at standard 5V logic levels. This is sufficient for a lot of purposes (including illuminating an LED) but not enough to operate actuators, motors, lamps and many other 'real-world' output devices. Fortunately, the problem of driving the vast majority of high voltage and high current loads can be easily solved

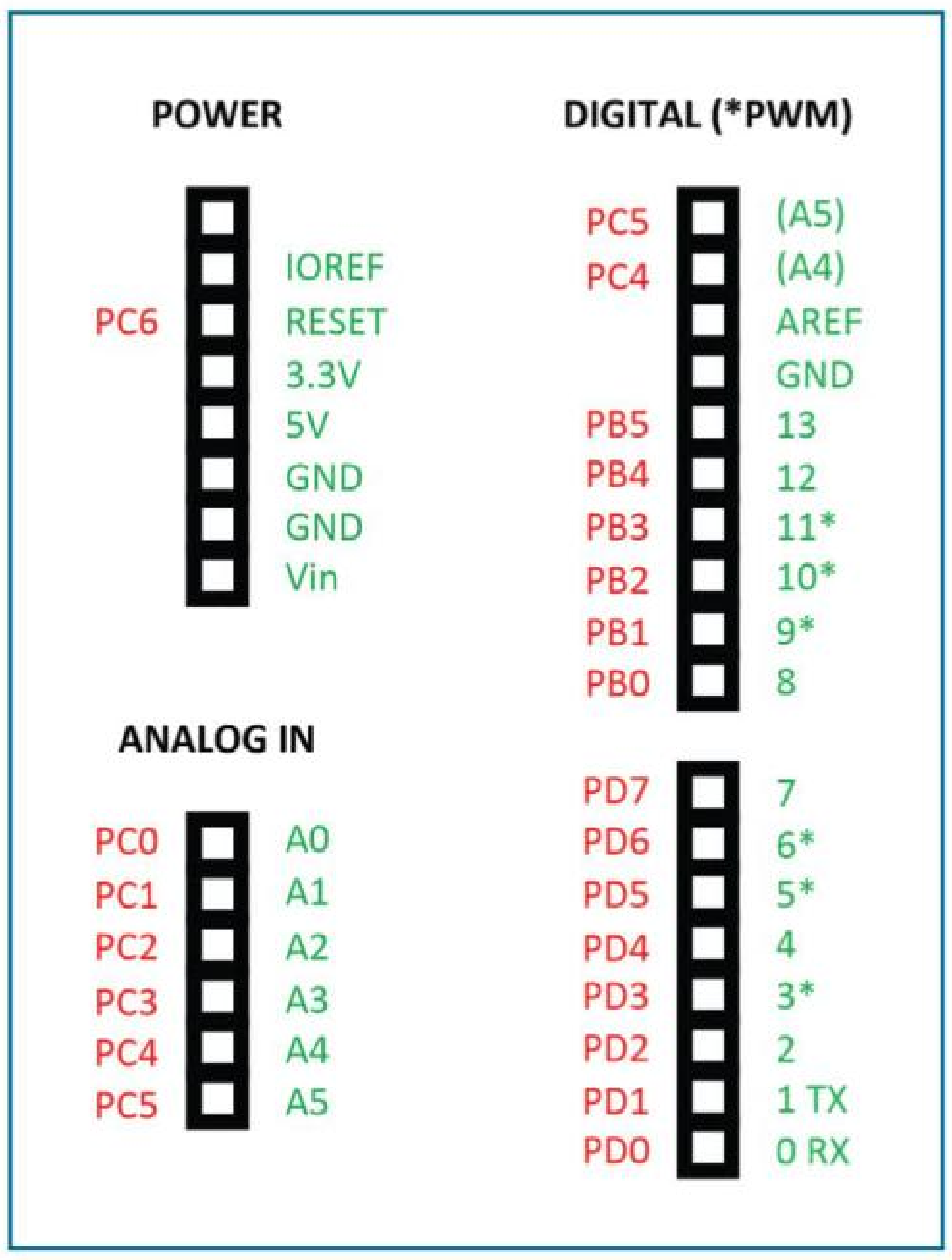

POWER
IOREF
PC6
RESET
3.3V
5V
GND
GND
Vin
ANALOG IN
PC0
A0
PC1
A1
PC2
A2
PC3
A3
PC4
A4
PC5
A5
DIGITAL (*PWM)
PC5
(A5)
PC4
(A4)
AREF
GND
PB5
13
PB4
12
PB3
11*
PB2
10*
PB1
9*
PB0
8
PD7
7
PD6
6*
PD5
5*
PD4
4
PD3
3*
PD2
2
PD1
1 TX
PD0
0 RX

Fig.2.1. The Arduino Uno's I/O pin assignment

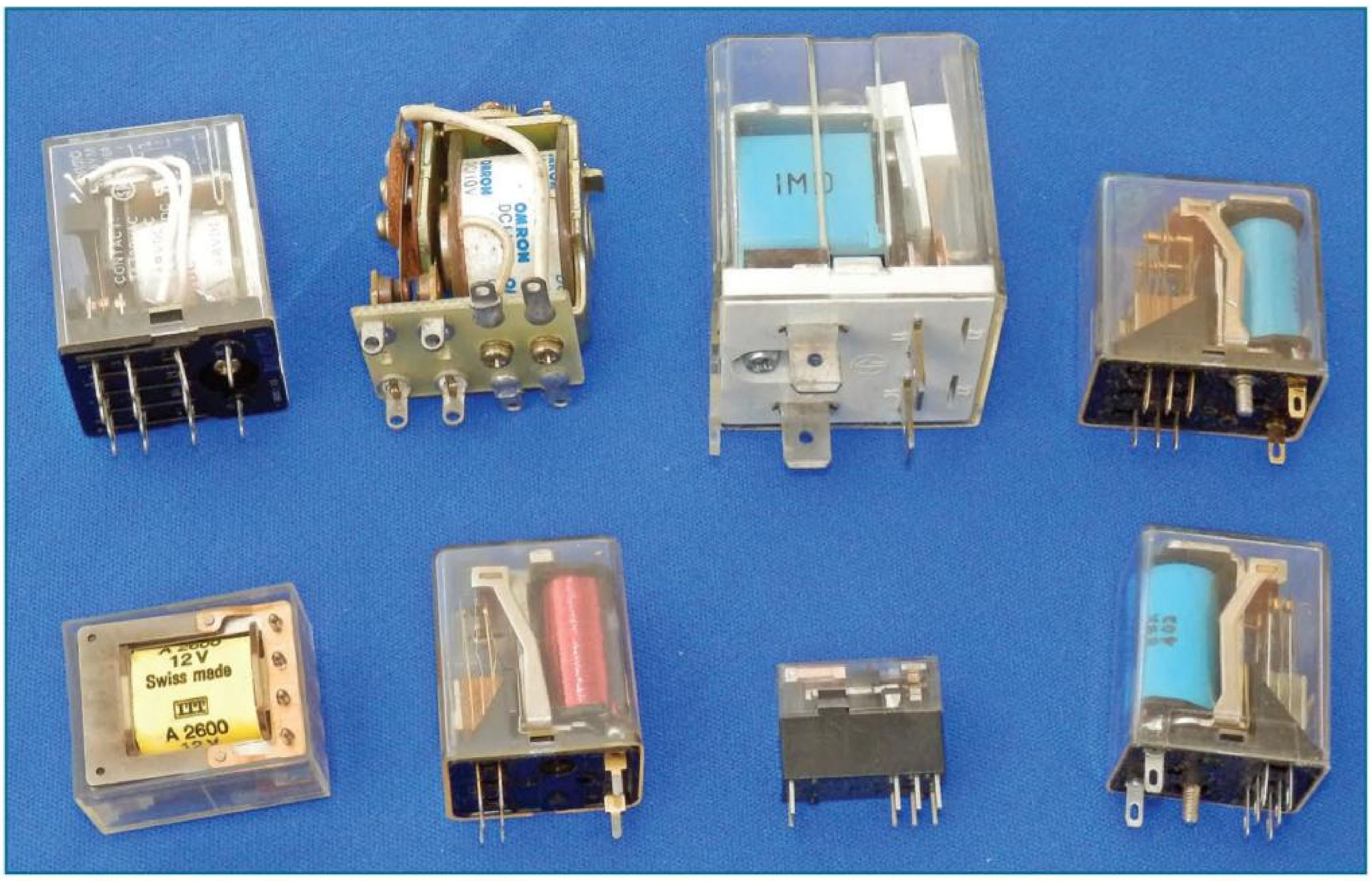

IMO
OMRON
12V
Swiss made
ITT
A 2600

Fig.2.2. A selection of common types of relays with contact ratings ranging from 1A to 20A

Parameter	Value
Nominal operating voltage	5V DC
Nominal operating current	73mA
Maximum load rating	AC 250V 10A, DC 30V 10A
Pull-in voltage (typical)	3.8V
DC coil resistance	70Ω
Power consumption (typical)	0.36W
Operating time (max.)	10ms
Release time (max.)	5ms
Contact resistance (max.)	0.11Ω
Operating life	100,000 operations at rated load
Maximum switching rate	30 operations per second

Table 2.1 Electrical specifications of a typical miniature PCB-mounting relay

using one or more miniature relays (see Fig.2.2). These electromechanical devices comprise a coil wound on a high-permeability core and a moving armature mechanically linked to a set of contacts that make and break when the device is actuated (see Fig.2.3). When sufficient current is applied to the coil of the relay the resulting magnetic field will cause the soft iron armature to pull-in and this in turn will open or close the relay's electrical contacts. A typical miniature PCB-mounted relay will operate from a 5V DC supply and its contacts will pull-in at typically 75% of this value. The specifications of such a relay are listed in Table 2.1.

It is important to note from Table 2.2 that the relay coil requires an operating current that's well beyond the output drive capability of the Arduino. We therefore need an interface that will provide the extra current required. Fortunately, this can often be little more than a low-power transistor and a handful of other components, as shown in Fig.2.4.

In Fig.2.4 the transistor can be almost any NPN type with a current gain of around 100, or more. Diode D1 counters the effects of the induced voltage that will appear across the relay coil as the current (and consequently the magnetic flux) collapses when the transistor reverts from a conducting to a non-conducting state. A typical value for R1 would be 2.2kΩ when using a relay coil that requires less than 200mA to operate (eg, a 700Ω coil rated at 12V). This value for R1 is sufficiently small to ensure that TR1 is driven into saturation when a high-state output voltage appears on the digital I/O line, but large enough to reduce the demand on the I/O port to around 2mA.

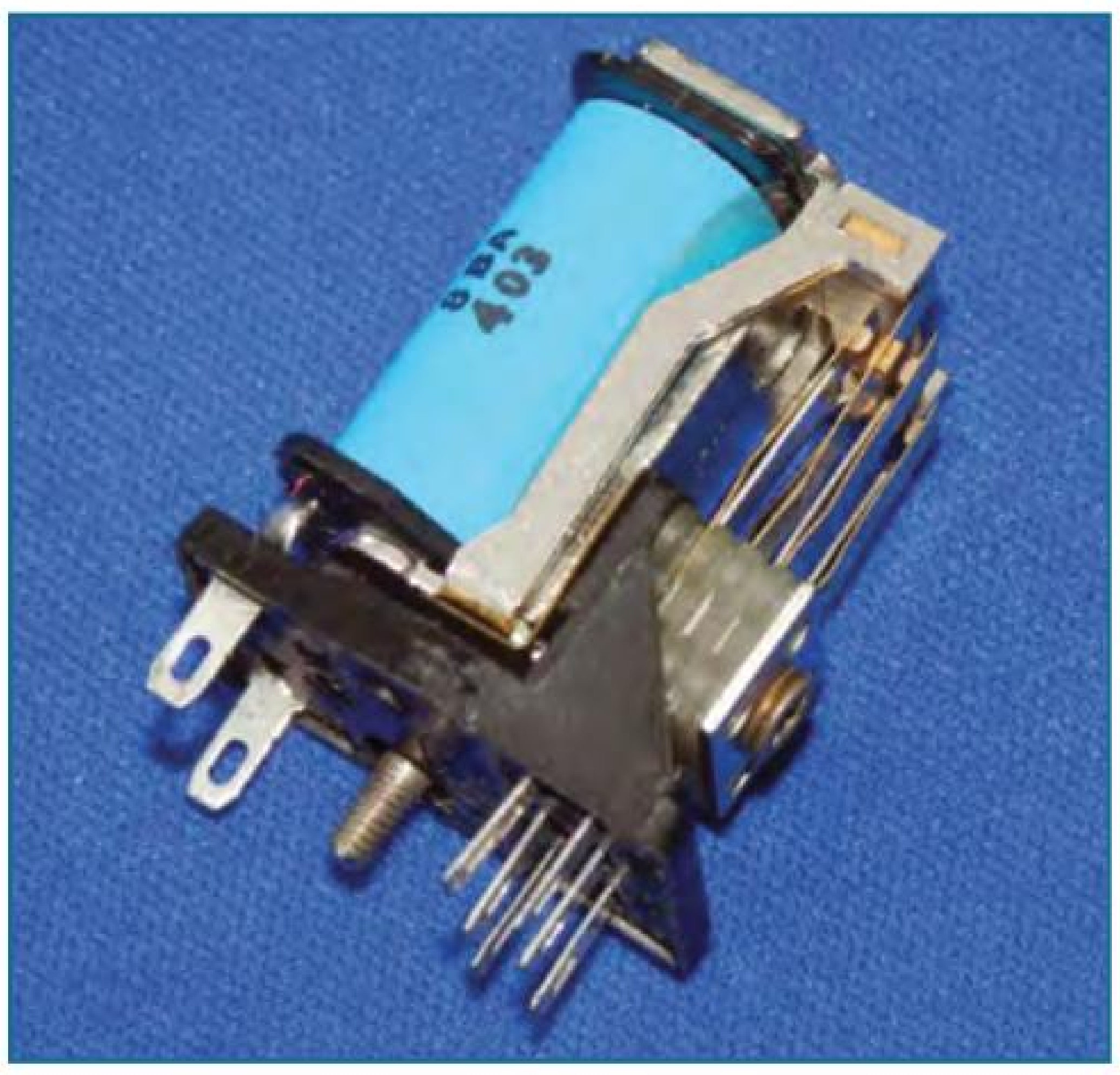


Fig.2.3. Internal arrangement of a typical relay showing the coil, armature and contacts

A neater alternative to using discrete components is the use of an integrated circuit output driver, such as the popular ULN2803. We will be looking at this chip in a future *Teach-In 2016* article, but for the moment, if you only have a couple of high current/high voltage loads to drive then a simple discrete circuit like the one shown in Fig.2.4 is all that you need.

Arduino World: Relay boards

Many simple control projects can be based on a ready-made relay board, avoiding the need to construct your own interface circuit. Fortunately, there are quite a few to choose from and the two most common types are fitted with either four or eight relays, with each relay having its own driver circuit.

Four-channel relay board

Fig.2.5 shows a typical four-channel relay board. The board has a transistor driver and an opto-isolator for each output channel. Similar boards can be purchased very cheaply (often less than £5) and so it is invariably more cost effective to purchase one of these boards rather than attempt to build one yourself.

Individual relays are normally fitted with single-pole changeover contacts (equivalent to an SPDT switch) and are commonly rated 250V AC at 10A or 30V DC at 10A. Inputs are usually TTL compatible and active *low* (in other words, they require a logic 0 output from the Arduino to operate).

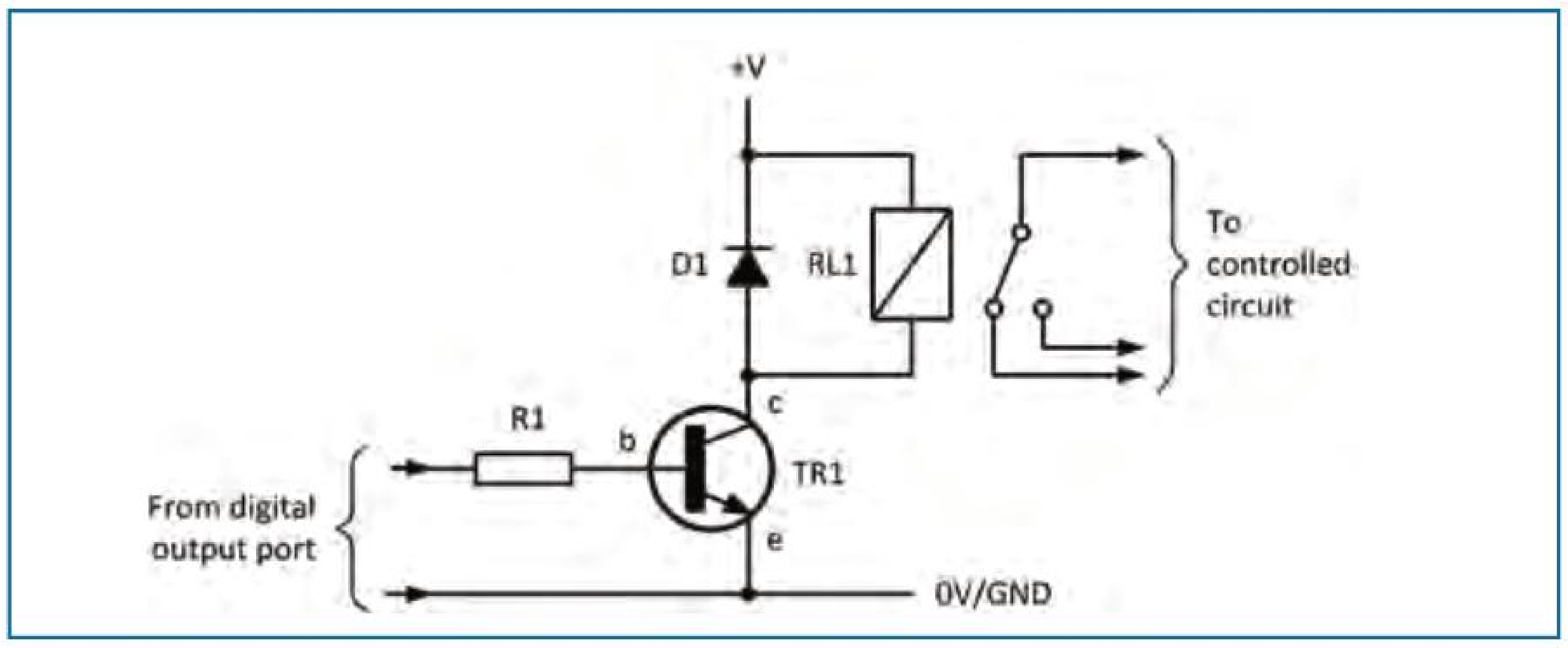


Fig.2.4. Simple single-transistor relay interface

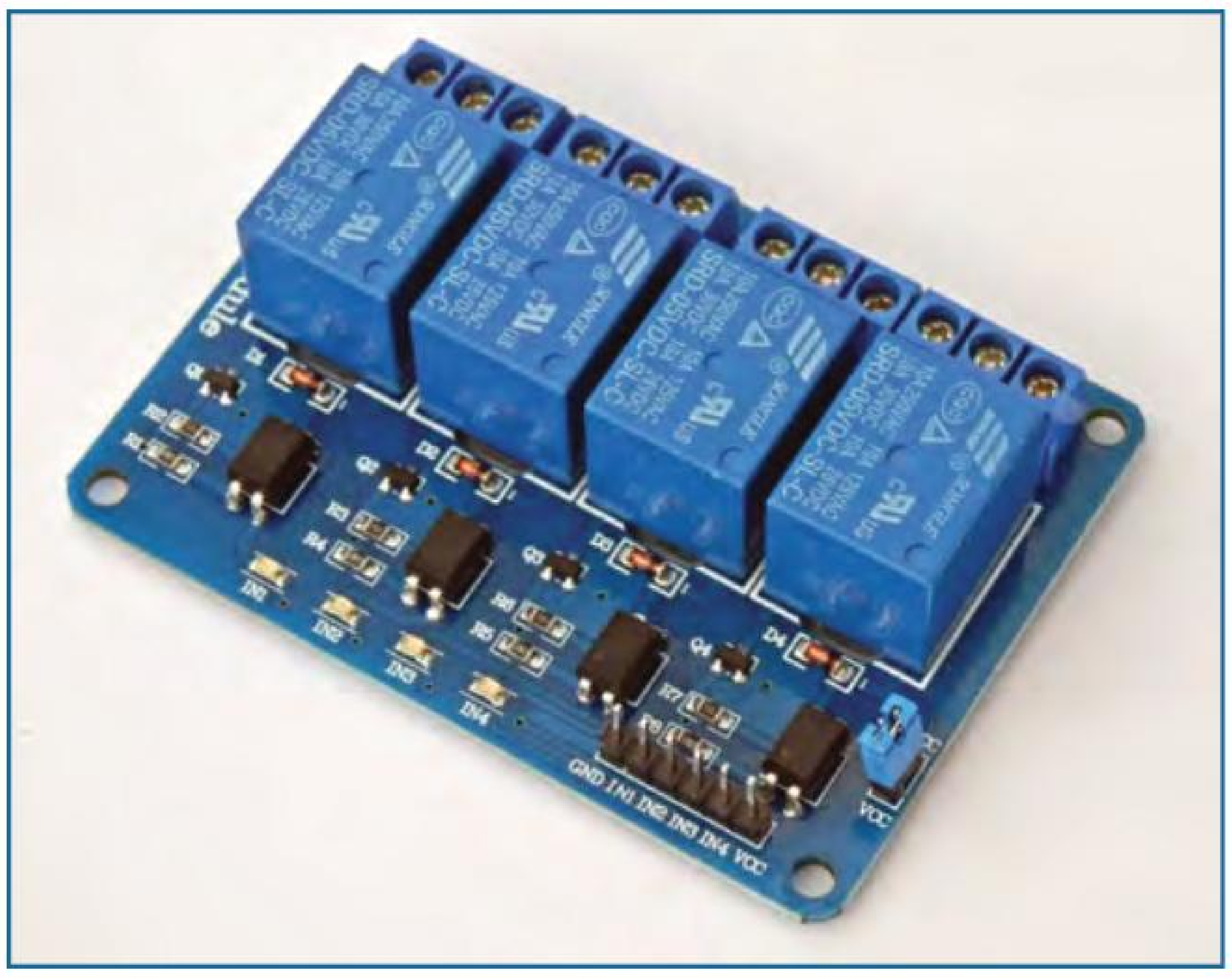


Fig.2.5. A four-channel relay interface board

Isolation

Many relay boards (like the one shown in Figs. 2.6) incorporate opto-isolators and this makes it possible to isolate the relay driver circuitry from the Arduino's circuitry (see Fig.2.7). However, in many applications this feature will not be required and the relay driver circuitry can then be operated from the same supply and ground connection as used by the Arduino itself.

Relay board connection

In Fig.2.8(a) the +5V and GND connections are common between the Arduino and the relay board. In this arrangement the relays must be 5V types and the only isolation between the Arduino and the load will be that afforded by the relay alone. This will usually be perfectly adequate for most applications, including switching mains loads at currents of up to several amps.

Fig.2.8(b) shows how higher-voltage (eg, 12V or 24V) relays can be used, while retaining a common ground (GND)

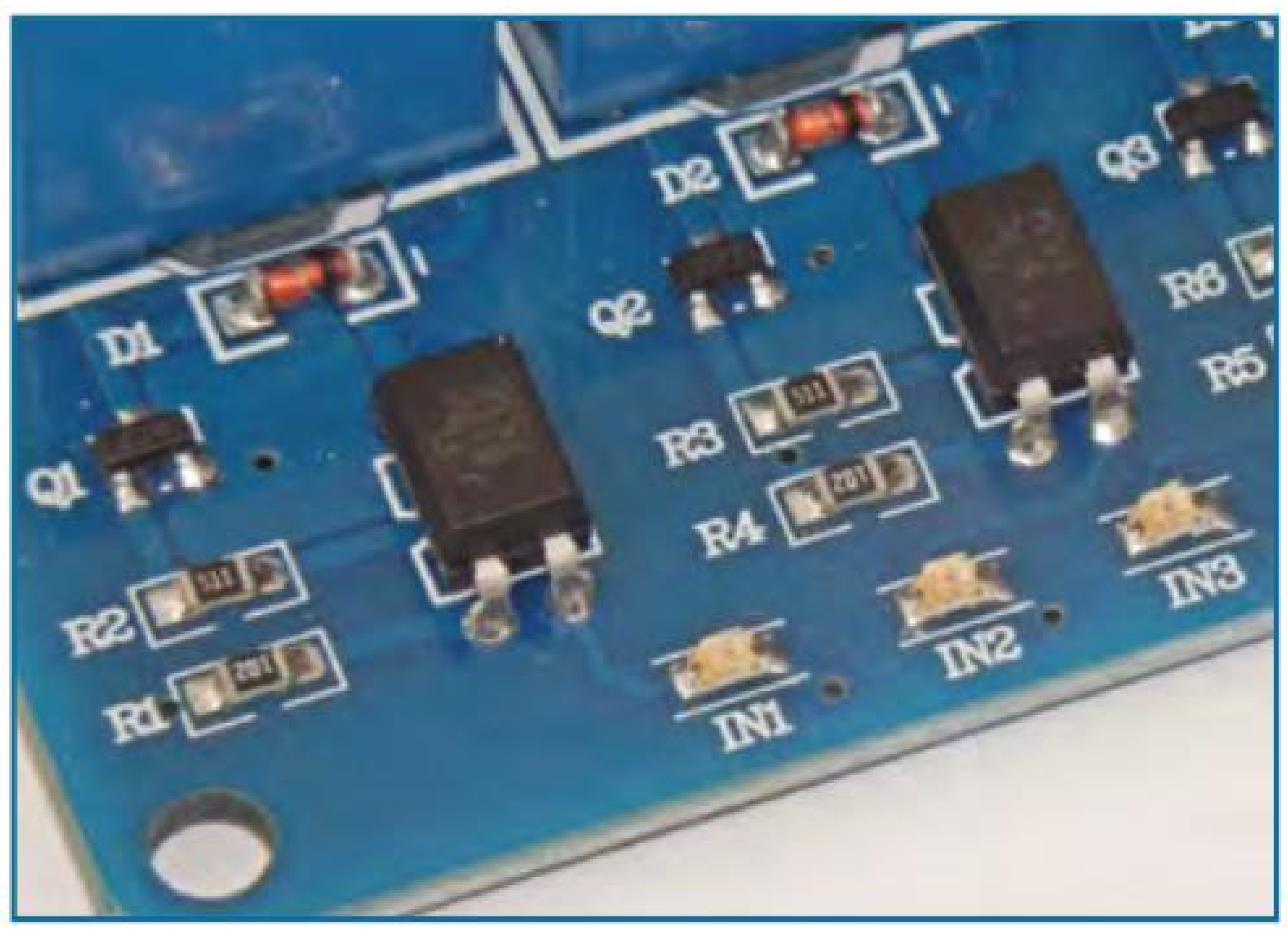


Fig.2.6. Transistor drivers and optical isolators on the four-channel relay board

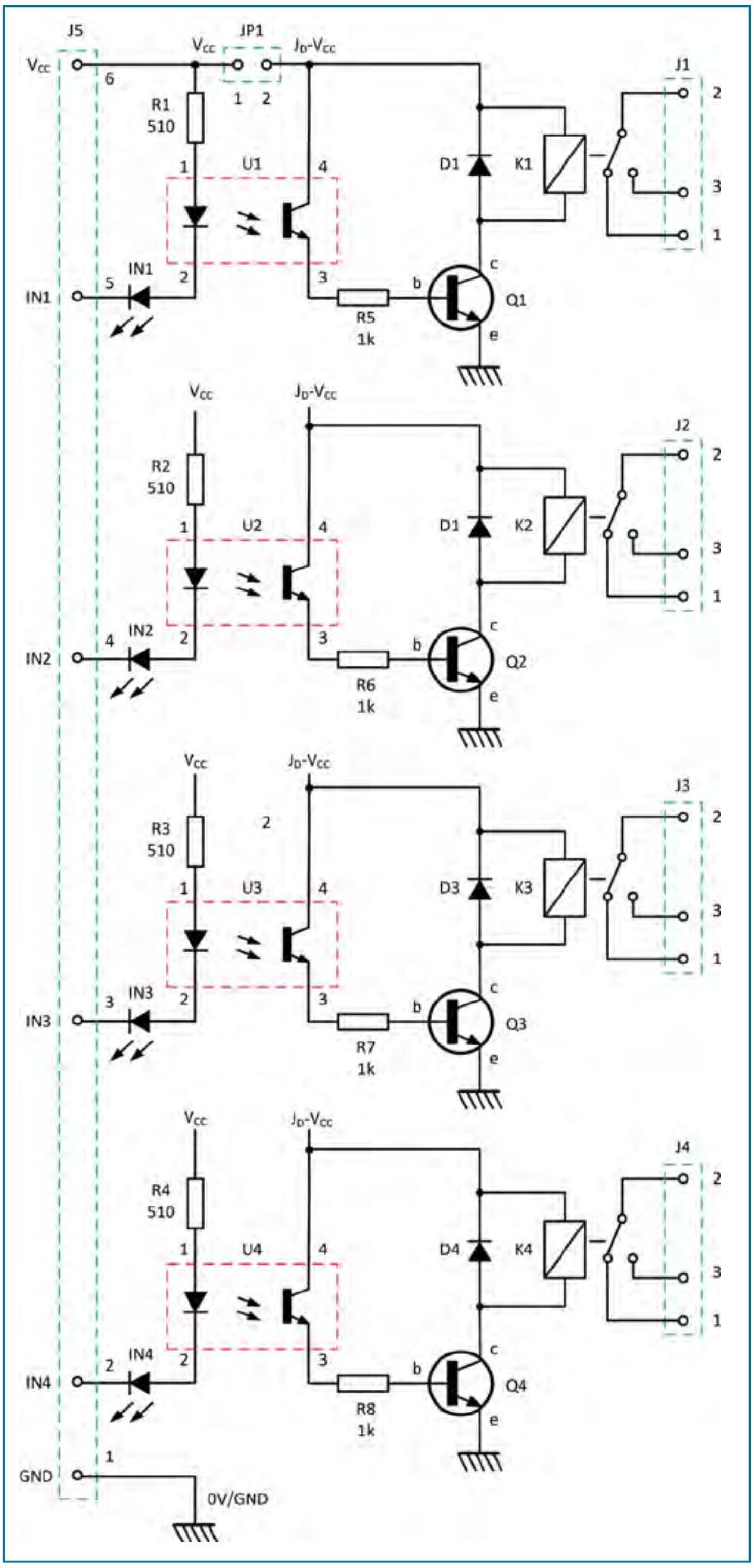
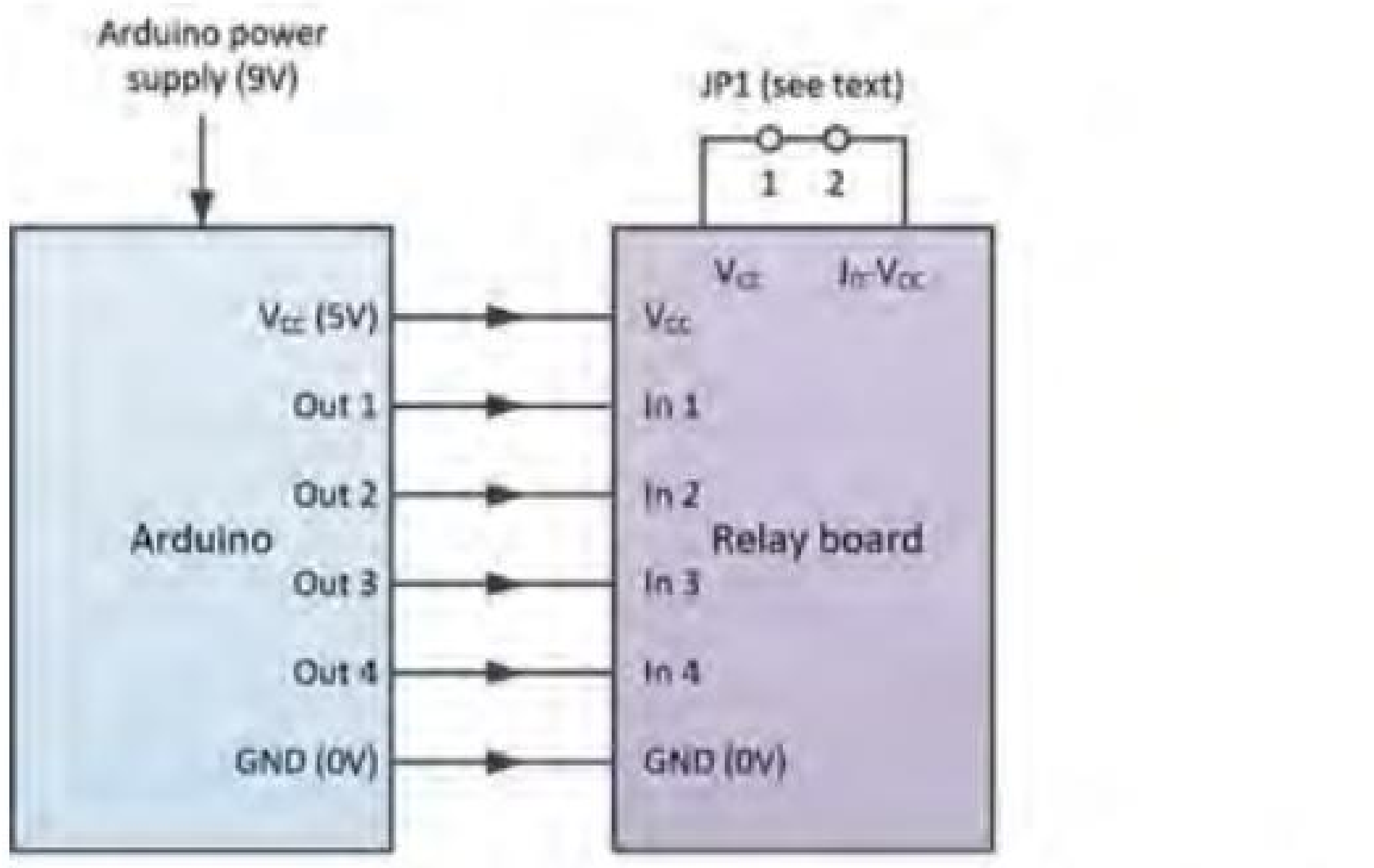
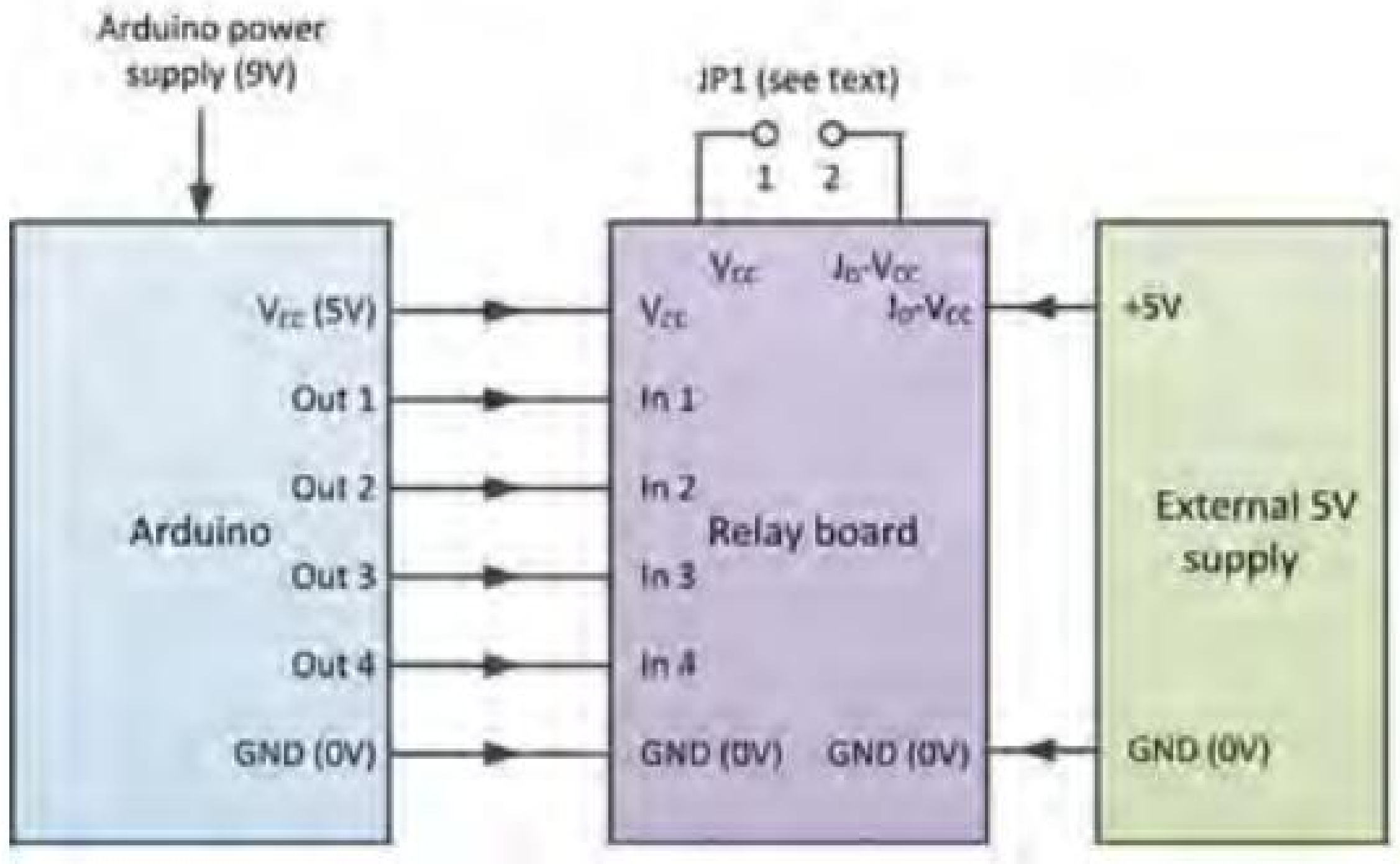

J5
VCC
JP1
JD-VCC
J1
6
1 2
R1
510
U1
D1
K1
IN1
5
R5
1k
Q1
b
c
e
R2
510
U2
J2
K2
IN2
4
R6
Q2
R3
510
U3
D3
J3
K3
IN3
3
R7
Q3
R4
510
U4
D4
J4
K4
IN4
2
R8
Q4
GND
1
0V/GND

Fig.2.7. Complete circuit of a four-channel relay board

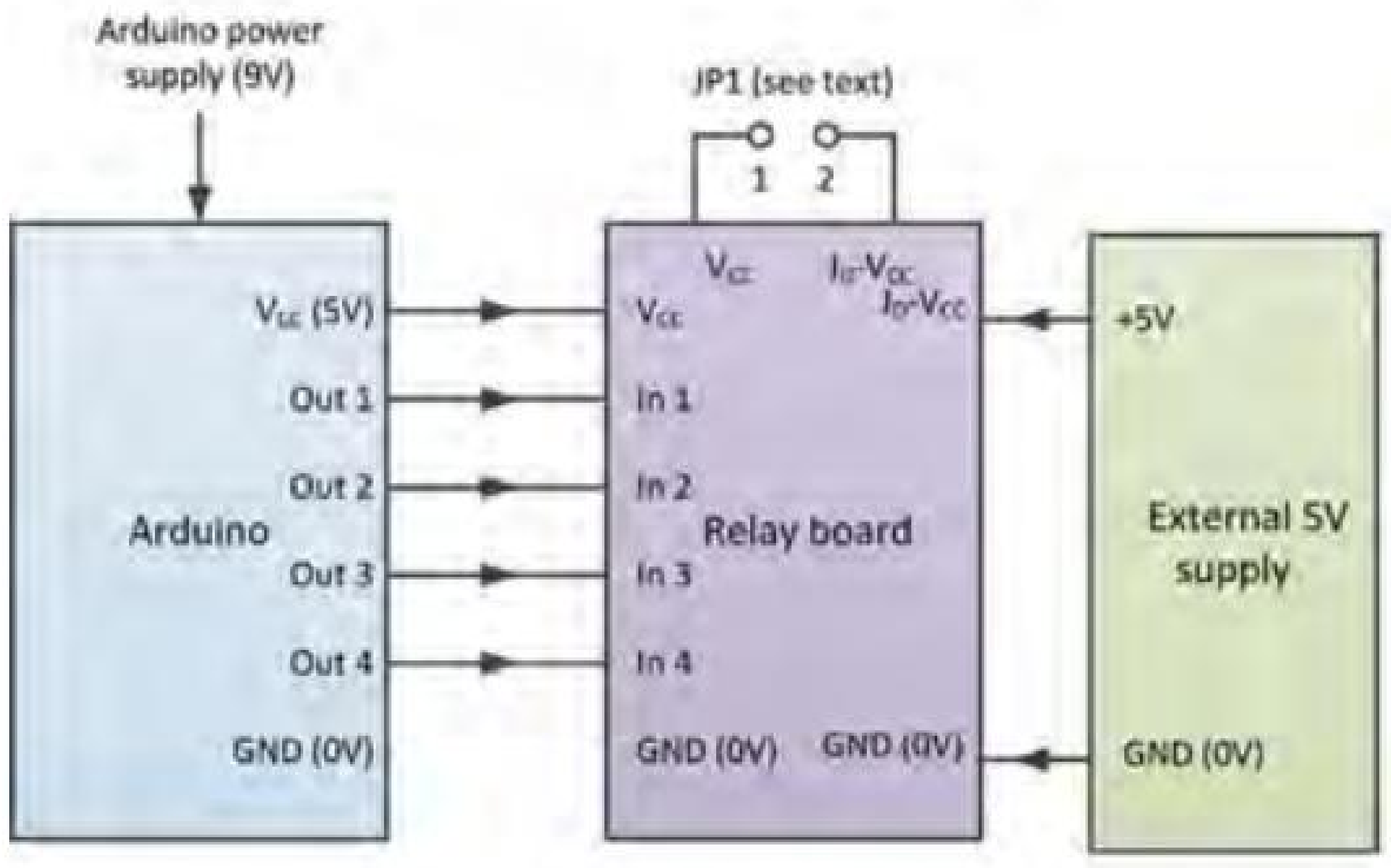
connection between the Arduino and the relay board. Higher power relays can be used for applications that involve switching currents of up to 20A. In all cases it is important to check the specifications of the relay that you plan to use and verify its suitability for use in a particular application.


Arduino power supply (9V)
JP1 (see text)
1 2
Arduino
VCC (5V)
Out 1
Out 2
Out 3
Out 4
GND (0V)
Relay board
VCC
JD-VCC
In 1
In 2
In 3
In 4
GND (0V)

(a) Arduino 5V relay supply with isolation provided by relays


Arduino power supply (9V)
JP1 (see text)
1 2
Arduino
VCC (5V)
Out 1
Out 2
Out 3
Out 4
GND (0V)
Relay board
VCC
JD-VCC
In 1
In 2
In 3
In 4
GND (0V)
+5V
External 5V supply
GND (0V)

(b) External 5V supply with common GND/0V


Arduino power supply (9V)
JP1 (see text)
1 2
Arduino
VCC (5V)
Out 1
Out 2
Out 3
Out 4
GND (0V)
Relay board
VCC
JD-VCC
In 1
In 2
In 3
In 4
GND (0V)
+5V
External 5V supply
GND (0V)

(c) External 5V supply and full optical isolation

Fig.2.8. Three possible relay board configurations providing different amounts of isolation

In Fig.2.8(c) we have shown a fully optically isolated arrangement in which there is no common ground connection between the Arduino and the relay board. This arrangement offers the greatest amount of isolation, together with improved noise immunity.

Eight-channel relay board

Fig.2.9 shows an eight-channel relay board. Like the four-channel board that we've just described, boards of this type are also available at low-cost from several sources. At under £10 they offer an extremely cost-effective means of controlling up to eight loads and at a cost that's considerably less than the cost of purchasing the individual components.

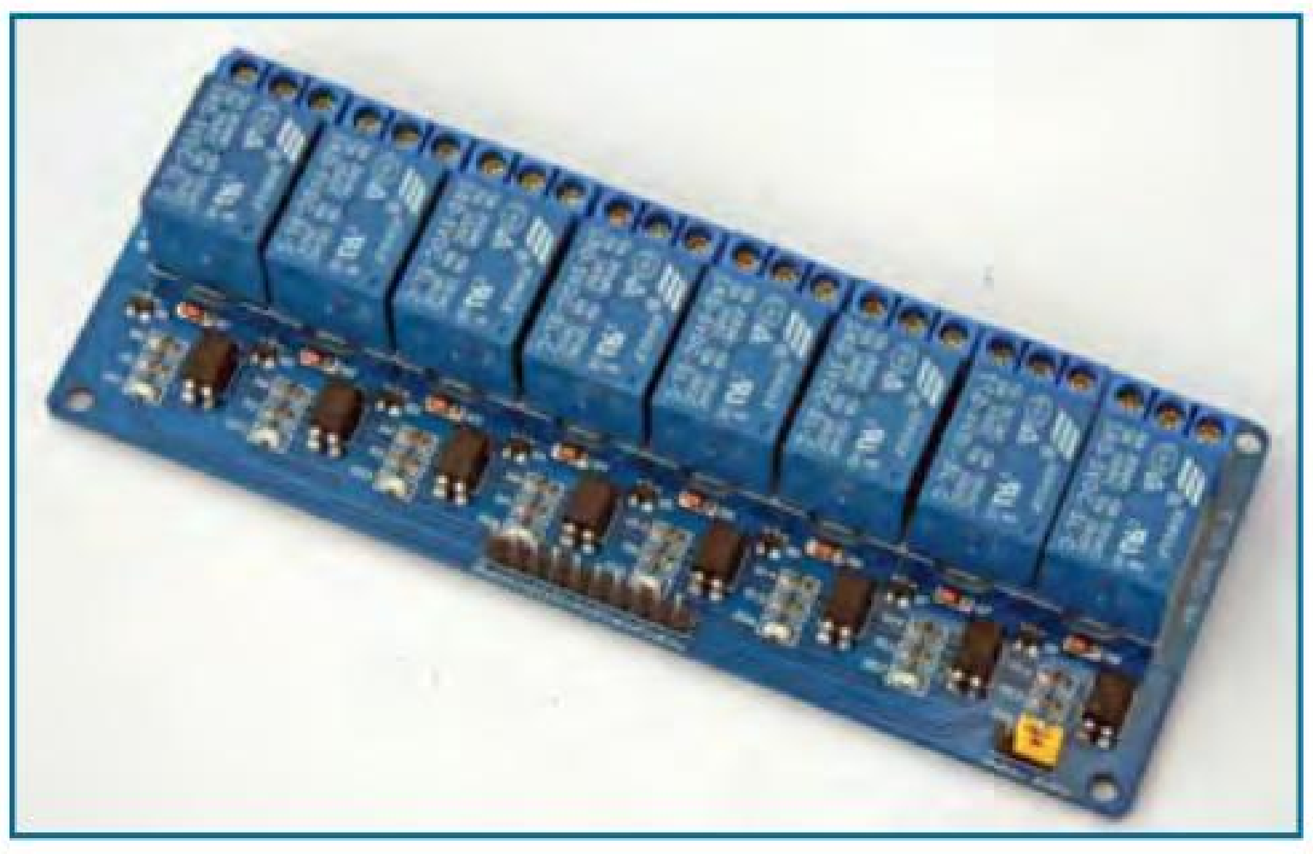


Fig.2.9. An eight-channel relay interface board

Coding relay outputs

Fortunately, it's very easy to control one or more relays using just a few lines of simple code. First, you will need to make sure that you define the digital output pins to which the relays are connected using a line of the form:

```
int pump = 5;  // Pump connected via a relay on digital pin-5
int heater = 6;  // Heater connected via a relay on digital pin-6
```

Next, you will need to add a couple of lines into the `setup()` code block, as follows:

```
pinMode(pump, OUTPUT);  // Pump is configured as an output
pinMode(heater, OUTPUT);  // Heater is configured as an output
```

The relays and their respective loads can be turned on and off incorporating the following lines of code at appropriate points in the main program loop:

```
digitalWrite(pump, LOW);  // Turn the pump off

digitalWrite(pump, HIGH);  // Turn the pump on

digitalWrite(heater, LOW);  // Turn the heater off

digitalWrite(heater, HIGH);  // Turn the pump on
```

Listing 1 shows a complete example where a fluid is heated and pumped in a continuous 30s cycle. Note that the main loop repeats indefinitely and can only be interrupted by using the Arduino's reset button.

Coding Quickstart : Understanding data types

Making decisions based on what's happening and then acting on this information in different ways is an essential pre-requisite of any programming language. C provides you with a variety of different conditional constructs that allow you to do this. Simple decisions can be made using nothing more than `if` and `else`, and loops can be controlled using `while`, `do while`, `for` and `loop`. We will look at all of these starting with `if` and `else`.

The `if` construct

The `if` construct is the most simple of all the conditional constructs. It is used when a statement (or a series of statements) should be executed when a particular condition prevails. The basic syntax is as follows:

```
if (conditional expression)
   // code to be executed if true,
   // each statement ending with ;
```

An example might be counting items into batches of 10 on a conveyor. Let's assume that we need to operate an LED when the count reaches (or exceeds) ten items. The following fragment of code would do this:

```
if (count >=10)
   digitalWrite(fullLED, HIGH);
```

If the value of count is less than 10 the condition evaluates false and the statement following the condition is then simply ignored. However, if the value of count is 10 or greater then the condition evaluates true and the statement following the condition is executed. In some applications it can be appropriate to use a series of `if` statements to detect various conditions and to act on them accordingly.

The `if ... else` construct

The `if ... else` construct is straightforward; its syntax is:

```
if (conditional expression)
   // code to be executed if true,
   // each statement ending with ;
else
   // code to be executed if false
   // each statement ending with ;
```

Here's a simple example. Let's assume that we are monitoring an analogue voltage and wish to set a threshold of 512 as the value at which a green LED should become illuminated and, below this value, we would like a red LED to be turned on. Our `if … else` construct would then look something like this:

```
if (inVoltage >=128)
   digitalWrite(greenLED, HIGH);
else
   digitalWrite(redLED, HIGH);
```

Unfortunately, this isn't quite the whole story. The red and green status LEDs should be mutually exclusive and so we might need to ensure that, when one LED is turned on the other LED is turned off. There are various ways that we could do this. We could either set them both off before we arrive at the `if else` construct or we could turn one on and the other off within a construct containing more than one statement (ie, a *compound* construct). Using the first method we might have:

```
// start with both LEDs off
digitalWrite(redLED, LOW);
digitalWrite(greenLED, LOW);
// now decide which LED to put on
if (inVoltage >=512)
   digitalWrite(greenLED, HIGH);
else
   digitalWrite(redLED, HIGH);
```

The other possibility is:

```
// Read the input voltage and
// put the red or green LED on
if (inVoltage >=512){
   digitalWrite(greenLED, HIGH);
   digitalWrite(redLED, LOW);
}
else{
   digitalWrite(redLED, HIGH);
   digitalWrite(greenLED, LOW);
}
```

Notice how in this example we've compounded several statements after the `if` and `else` and that that we've introduced curly braces, { and }, to make the logic clear and unambiguous. Of course, at some point earlier in the code we would have to define the pins that we are using to control the two LEDs and initialise the variables (`inVoltage`, `redLED` and `greenLED`).

Listing 2.2 provides you with a complete example that you can run using the excellent Arduino Uno simulator that we introduced last month. Fig.2.10 shows the code running in the simulator. Notice how we've entered the LED pin numbers as well as the pin used for the analogue voltage input in the appropriate simulator boxes. You can vary the input voltage by using the slider in the bottom right of the screen, noting how the status LEDs respond, changing when the input voltage reaches the 512 threshold. Finally, it's worth noting how UnoArduSim reports the current values of all of the variables in the bottom left-hand window.

Listing 2.1: Example of typical relay board code

```
/* Hot fluid cycle: heat for 24s and then pump for 6s */

int pump = 5;  // Pump connected via a relay on digital pin-5
int heater = 6;  // Heater connected via a relay on digital pin-6

void setup() {
   pinMode(pump, OUTPUT);  // Pump is configured as an output
   pinMode(heater, OUTPUT);  // Heater is configured as an output
}

void loop() {
   digitalWrite(pump, LOW);  // Turn the pump off
   digitalWrite(heater, HIGH);  // Turn the heater on
   delay(24000);  // Wait 24s
   digitalWrite(heater, LOW);  // Turn the heater off
   digitalWrite(pump, HIGH);  // Turn the pump on
   delay(6000);  // Wait 6s
}
```

Listing 2.2: Using a compound `if ... then` *construct*

```
/* Simple decision making using a compound if..then
   construct
*/

int redLED = 13;      // red LED on digital pin 13
int greenLED = 12;    // green LED on digital pin 12
int inAnalogue = A0;  // analogue input pin 0
int inVoltage = 0;    // initialise the variable

void setup()
{
      pinMode(redLED, OUTPUT);
      pinMode(greenLED, OUTPUT);
}

void loop()
{
      // get the input voltage
      inVoltage = analogRead(inAnalogue);
      // illuminate the green or red status LEDs
      if (inVoltage >= 512){
            digitalWrite(redLED, HIGH);
            digitalWrite(greenLED, LOW);
      }
      else{
            digitalWrite(greenLED, HIGH);
            digitalWrite(redLED, LOW);
      }
}
```

Conditions

In the last example you should have noticed the >= `condition` that we used to find out whether the input voltage has exceeded the threshold value of 512. The 'greater than or equal to' condition isn't the only one that we have to play with, as Table 2.2 shows.

The `while` construct

Code	Meaning	Notes
a == b	a is equal to b	True if a and b have the same value
a != b	a is not equal to b	True if a and b have different values
a > b	a is greater than b	True if a is larger than b (but not true if they have the same value)
a < b	a is less than b	True if a is smaller than b (but not true if they have the same value)
a >= b	a is greater than or equal to b	True if a is larger than b (and also true if they have the same value)
a <= b	a is less than or equal to b	True if a is smaller than b (and also true if they have the same value)

Table 2.2 Conditions

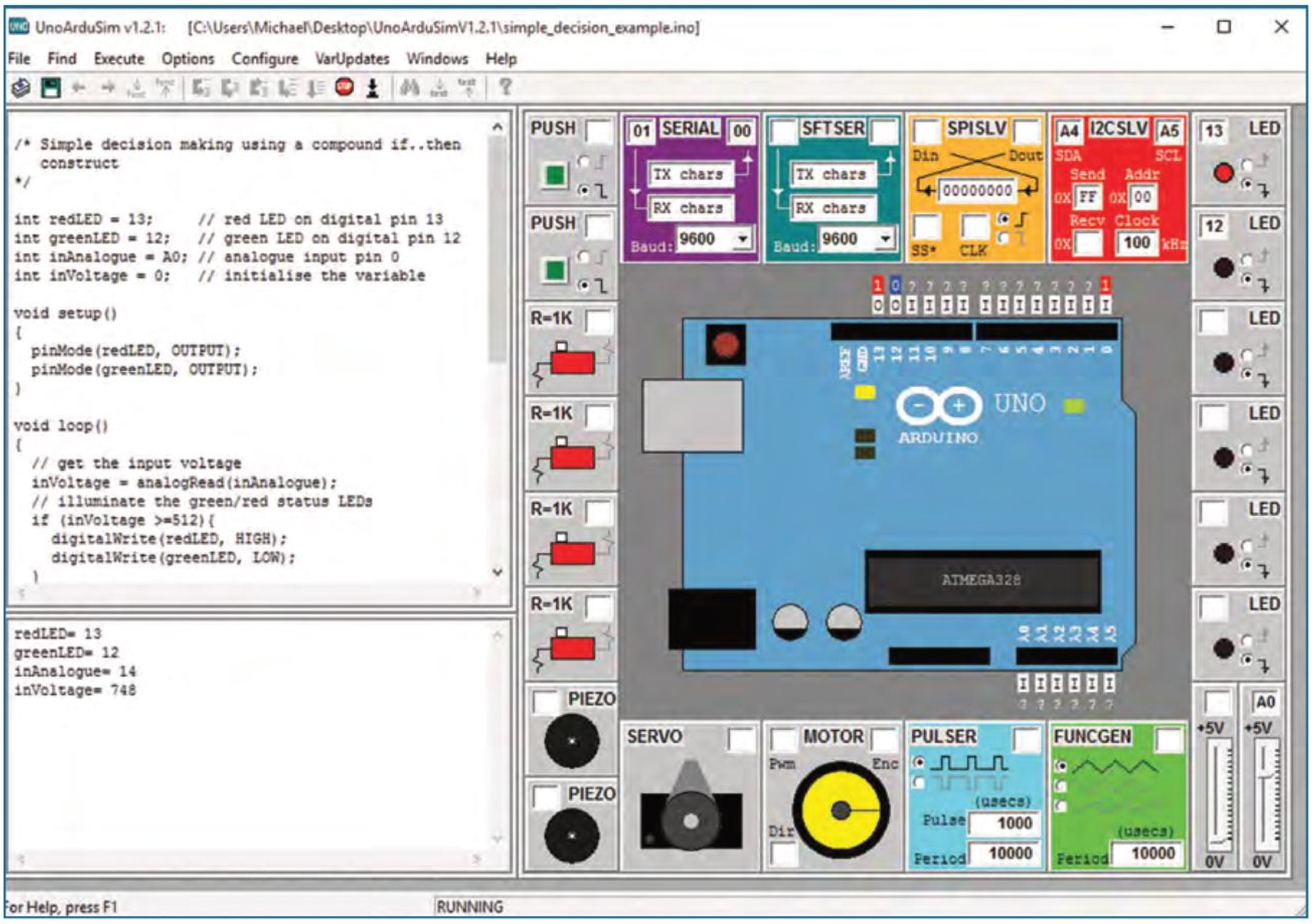
The `while` construct provides you with a means of continuously executing one or more statements until a condition evaluates false. The loop containing the statement (or statements) will continue to be executed as long as the condition remains true – but, as soon as it becomes false the loop will terminate and execution will continue with the next subsequent statement. The basic syntax is:

```
while (conditional expression){
   // statements to be executed if true,
   // each ending with ;
}
```

Here's an example that shows how a belt motor could be controlled using a while loop. The belt motor will run for as long as it takes for an item placed on the belt to reach a limit switch. Note that we must check the status of the limit switch inside the loop. If we forget to do this the motor will run forever!

```
while (limitSwitchStatus == LOW){
    // Limit not reached so run the motor
    digitalWrite(motorRun, HIGH);
// Check to see if anything has changed?
limitSwitchStatus = digitalRead(limitSwitch);
}
```

By making the conditional expression dependent on the value of a counter modified inside the loop we have a simple means of performing one or more statements a predetermined number of times, as follows:


UnoArduSim v1.2.1: [C:\Users\Michael\Desktop\UnoArduSimV1.2.1\simple_decision_example.ino]
File Find Execute Options Configure VarUpdates Windows Help
PUSH
PUSH
R=1K
R=1K
R=1K
R=1K
PIEZO
PIEZO
SERIAL
TX chars
RX chars
Baud: 9600
SFTSER
TX chars
RX chars
Baud: 9600
SPISLV
Din
Dout
00000000
SS*
CLK
I2CSLV
SDA
SCL
Send
Addr
0X FF
0X 00
Recv
Clock
100 kHz
UNO
ARDUINO
ATMEGA328
SERVO
MOTOR
Pwm
Enc
Dir
PULSER
(usecs)
Pulse 1000
Period 10000
FUNCGEN
(usecs)
Period 10000
LED
A0
+5V
0V
For Help, press F1
RUNNING

```
/* Simple decision making using a compound if..then
   construct
*/

int redLED = 13;     // red LED on digital pin 13
int greenLED = 12;   // green LED on digital pin 12
int inAnalogue = A0; // analogue input pin 0
int inVoltage = 0;   // initialise the variable

void setup()
{
  pinMode(redLED, OUTPUT);
  pinMode(greenLED, OUTPUT);
}

void loop()
{
  // get the input voltage
  inVoltage = analogRead(inAnalogue);
  // illuminate the green/red status LEDs
  if (inVoltage >=512){
    digitalWrite(redLED, HIGH);
    digitalWrite(greenLED, LOW);
  }
```

```
redLED= 13
greenLED= 12
inAnalogue= 14
inVoltage= 748
```

Fig.2.10. Using UnoArduSim to simulate the execution of Listing 2.2

```
count = 0;
while(count < 50){
  // code to be executed 50 times
  // each statement ending with ;
  count = count+1;
}
```

In this wait loop we increment the counter on every pass through the loop until it reaches 50, at which point the conditional expression evaluates to false and execution continues with the next statement in the code. Note this neater way of incrementing the count value, as follows:

```
count = 0;
while(count < 50){
  // code to be executed 50 times
  // each statement ending with ;
  count++;
}
```

In this case, `count++` is used to 'post-increment' the value of `count`. In other words, it takes the current value of `count`, adds one to it and places the new value back into the `count` variable.

Finally, here's an example showing how a simple wait loop could be used to flash an alarm LED ten times:

```
flashCount = 0;
while(flashCount < 10){
   digitalWrite(alarmLED, HIGH);
   delay(500); // wait half a second
   digitalWrite(alarmLED, LOW);
   delay(500); // wait half a second
   flashCount++;
}
```

The do ... while construct

The do ... while loop works in a similar fashion to the while loop, but with the exception that the condition is tested at the end of the loop, not the beginning. This means that the statements within the loop will always be executed at least once. The syntax is as follows:

```
do {
    // code to be executed at least once,
// each statement ending with ;
} while (conditional expression);
```

Here's an example of reading a pressure sensor and allowing it a short time for its output to reach a steady value:

```
do {
    delay(100);
    // wait for the value to settle
cp = readPressure();
// read the pressure sensor
}
while (x < 10);
```

In this example we are calling the `readPressure()` function 10 times before arriving at the final value returned from the sensor.

The for loop construct

The `for` loop is widely used in almost every computer language, and C is no exception. The construct is used to repeat a statement (or series of statements) whenever a condition evaluates true. If the condition evaluates false then the loop is exited and execution continues with the statement that immediately follows the loop. The `for` loop must be initialised at the outset and thus is a little more complex than the `while` loop. The basic syntax is:

```
for(loop initialization, conditional expression, increment){
   // statements to be executed if true,
   // each ending with ;
}
```

As with the while loop, a counter is often used to control the loop and this is incremented or decremented each time round the loop. This makes the construct ideal for use in any repetitive application, for example, checking the status of a number of I/O lines. It is important to remember that loop initialisation occurs only once and before the loop is executed for the first time.

The next code fragment shows how the ASCII character set can be sent to the serial printer. Note that, for this to run, we would first need to initialise the serial port interface using a line such as `Serial.begin(9600)`. Note also that we have declared the count variable, `i`, within the loop initialisation itself.

```
for (int i = 0; i <= 63; i++)
{
      testValue = 64 + i;
      Serial.print(testValue);
      Serial.print(“\n”);
      delay(100);
}
```

Program structure and layout

By now you should have gained some idea of what Arduino code looks like and how it is structured but before we go any further it is well worth explaining the layout of a C program in a little more detail. You may have noticed that the first few lines of code in a program usually take the form of a heading enclosed between pairs of characters, /* and */, which constitute a comment block. Everything between these two characters is taken as plain text and, since this has no effect on program execution you can use as many lines of text here as you want.

The title comment block is usually followed by a number of variable declarations. The reason behind this is simply that, in the C language, variables *must always be declared* before they are used. In fact, declarations don't have to be placed at the beginning of the program code but the point at which they are declared (ie, their position in the program) can impose restrictions on the scope over which they can be used. However, since we often need to use variables on a global basis (ie, anywhere in our program code) we will often place them *before* any of the other code. Declarations involve assigning a variable type (see last month), a name and (optionally) an initial value.

Next follows code that's used for setting up. This code is placed in a function called `setup()` and it is executed at the beginning and only once. The `setup()` function is often used to specify the pin modes (ie, input or output) and to configure the Arduino's serial monitor, but if they are not being used the `setup()` function can simply be left empty.

The main program code is written inside a loop that executes forever (or until the reset button is pressed or the power is removed). This `loop()` function contains the functions that will execute when the program is being run. Each function takes the form of a block of code that is executed whenever the function is called. Functions can be the ones that are built into the language or they can be user-defined. This feature allows us to extend the basic language for our own needs with our user-defined functions calling other functions (both user-defined and in-built) as and when required. Function declarations take the form of one or more statements enclosed between curly braces, { and }. Note that each individual statement must end with a semi-colon, ;.

As well as the block comments that we mentioned earlier, comments can be placed in-line. These consist of plain text appearing after two // characters and added at the end of the line to which they apply. As previously mentioned, comments provide us with a useful reminder of what's going on in the code and they can be invaluable when maintaining and debugging a program.

D1 (green)	D2 (red)	Condition
off	off	Alarm waiting to be set
on	off	Alarm set and waiting to be triggered
off	on	Alarm triggered and waiting to be cancelled

Table 2.3: Status indication for the simple Arduino-based security alarm

Listing 2.3: Code for the simple Arduino-based security system

```
* Single zone alarm with SET and CANCEL buttons */

int triggerInput = 7; // Break to trigger alarm
int setButton = 11; // Alarm SET button
int cancelButton = 12; // Alarm cancel button
int alarmSound = 4; // Siren
int setLED = 5; // Alarm SET LED
int alarmLED = 6;  // Alarm triggered LED
int setStatus = LOW; // SET button status
int cancelStatus = LOW; // CANCEL button status
int triggerStatus = LOW; // Trigger status

void setup()
{
     pinMode(triggerInput, INPUT);
     pinMode(setButton, INPUT);
     pinMode(cancelButton, INPUT);
     pinMode(alarmSound, OUTPUT);
     pinMode(setLED, OUTPUT);
     pinMode(alarmLED, OUTPUT);
     digitalWrite(alarmSound, LOW);
}

void loop()
{
     // Wait for set Button
     setStatus = LOW;
     while (setStatus == LOW && triggerStatus == LOW)
          // Loop must be closed to set the alarm
     {
          // Check to see if SET button has been pressed
          setStatus = digitalRead(setButton);
     }

     // Alarm has been set
     digitalWrite(setLED, HIGH);

     while (triggerStatus == LOW)
     {
          // Check if the alarm has been triggered
          triggerStatus = digitalRead(triggerInput);
     }

     //Alarm has been triggered
     digitalWrite(setLED, LOW);
     digitalWrite(alarmLED, HIGH);
     digitalWrite(alarmSound,HIGH);

     while (cancelStatus == LOW)
     {
          // Check if the CANCEL button has been pressed
          cancelStatus = digitalRead(cancelButton);
     }

     // Alarm has been cancelled
     triggerStatus = LOW;
     cancelStatus = LOW;
     // stop the alarm sound
     digitalWrite(alarmSound,LOW);
     // and also reset the LED indicators
     digitalWrite(alarmLED, LOW);
     digitalWrite(setLED, LOW);
}
```

Indenting (often by three or four spaces) is used to assist with program readability. This becomes particularly important when functions are enclosed within other functions. Finally, Fig.2.11 illustrates the various structural and layout features discussed here.

Get Real : A simple Arduino-based security systems

In this month's *Get Real* we are going to use the Arduino Uno as the basis of a very simple security system. Once again, we've minimised the need for anything much in the way of additional hardware, so you will only need a mini-breadboard and a few commonly available components to try it out.

You will need:

Arduino Uno with power supply
USB Type-A to Type-B cable
Computer with an available powered USB port
Mini-breadboard with a selection of coloured connecting leads
1 standard red LED (D2)
1 standard green LED (D1)
2 330Ω resistors (R1 and R2)
2 10kΩ resistors (R3 and R4)
1 4.7kΩ resistor (R5)
2 miniature push-button switches (S1 and S2)
Proximity switches (as required)
1 piezoelectric sounder (PZ1) (must be DC type)

Circuit

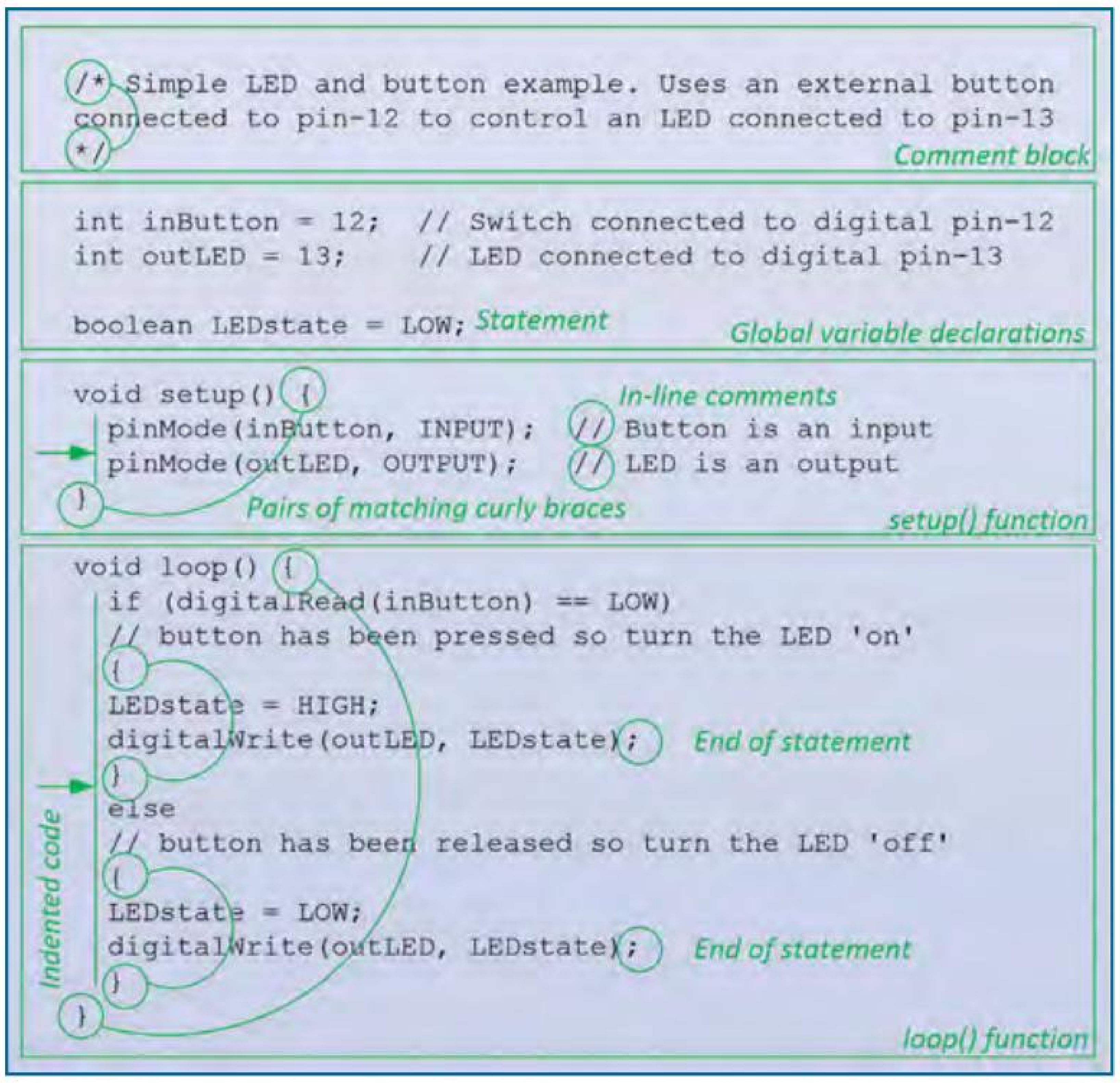
The complete circuit of our simple Arduino-based security system is shown in Fig.2.12. It uses six of the Uno's digital I/O lines; three of these are configured as inputs and three as outputs.

Two momentary action push-button switches, S1 and S2, are used to SET and CANCEL the alarm. The former of these switches is sensed by digital I/O pin-11, while the latter is sensed by digital I/O pin-12. The input loop is connected between digital I/O pin-7 and ground with R5 acting as a pull-up resistor so that the input will go 'high' whenever the loop is broken.

The green (SET) status indicator, D1, is driven by digital I/O pin-5 and the red (ALARM) status indicator, D2, is connected to digital I/O pin-6. The piezoelectric sounder (buzzer) is connected to digital I/O in-4. Note that the sounder needs to be a DC-operated component (not one that requires AC excitation).

Physical layout

The components are shown mounted on the mini-breadboard in Fig.2.13. The two status indicator LEDs will need to be connected with the correct polarity (see Fig.1.18 in last month's *Teach-In 2016*). If the layout proves problematic you could use a larger breadboard or a prototype shield (more of this in a future *Teach-In 2016*),



```
/* Simple LED and button example. Uses an external button
connected to pin-12 to control an LED connected to pin-13
*/

int inButton = 12;  // Switch connected to digital pin-12
int outLED = 13;    // LED connected to digital pin-13

boolean LEDstate = LOW;

void setup() {
  pinMode(inButton, INPUT);  // Button is an input
  pinMode(outLED, OUTPUT);   // LED is an output
}

void loop() {
  if (digitalRead(inButton) == LOW)
  // button has been pressed so turn the LED 'on'
  {
  LEDstate = HIGH;
  digitalWrite(outLED, LEDstate);
  }
  else
  // button has been released so turn the LED 'off'
  {
  LEDstate = LOW;
  digitalWrite(outLED, LEDstate);
  }
}
```

Comment block
Statement
Global variable declarations
In-line comments
Pairs of matching curly braces
setup() function
End of statement
Indented code
End of statement
loop() function

Fig.2.11. A simple Arduino program with various structural features identified

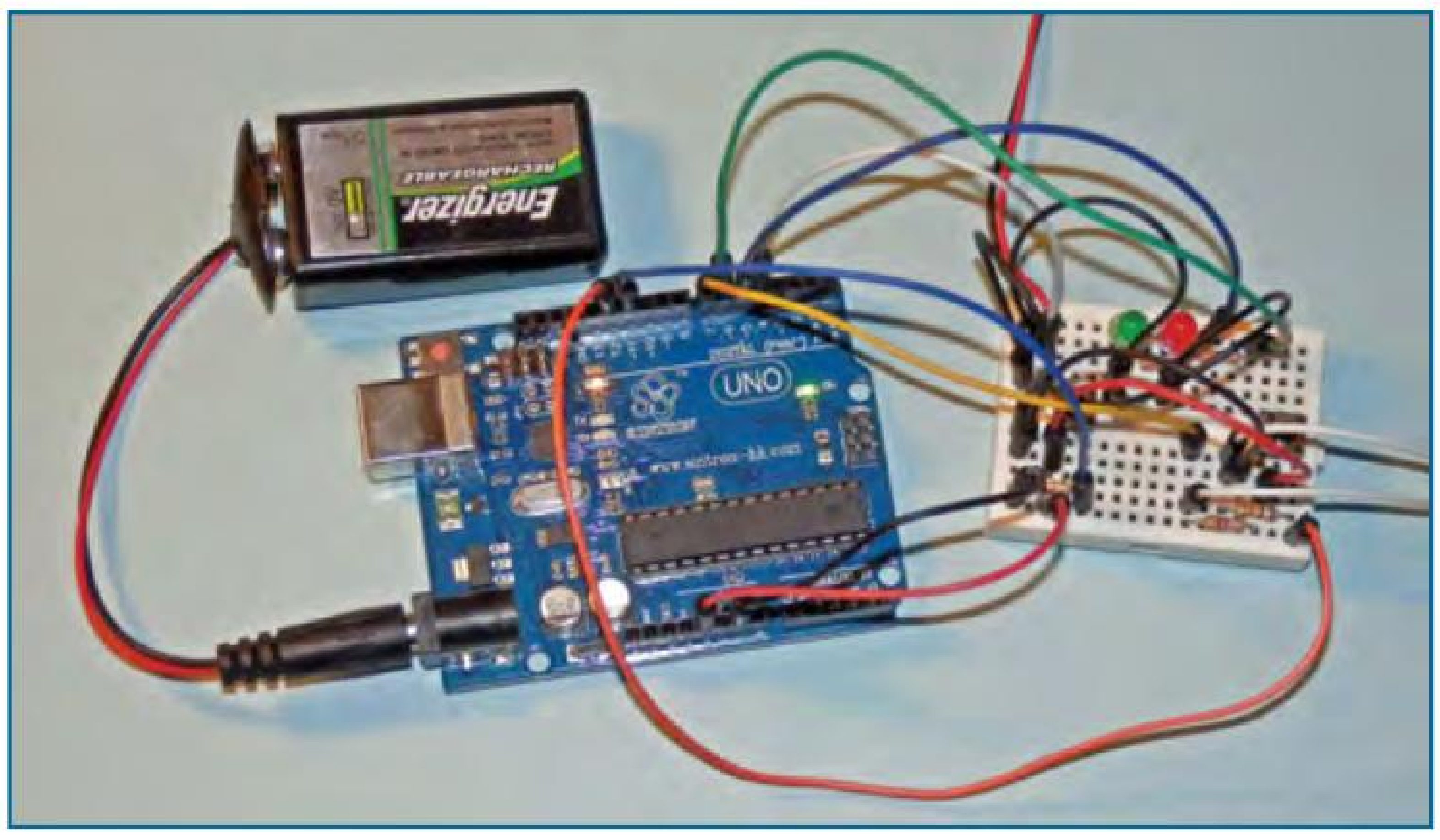


Fig.2.14. Actual breadboard arrangement

The input to digital I/O pin-7 is effectively a closed-circuit loop which, when broken, triggers the alarm. In a retail environment this can take the form of a continuous loop of insulated wire attached to any products that need to be protected. In order to remove an item the loop must be broken and this, in turn, will trigger the alarm. In other applications the loop can comprise one or more magnetically operated proximity switches, as shown in Fig.2.15. These are designed for discrete protection of doors and windows and they comprise a pair of moulded parts that need to be mounted adjacent to one another when the door or window to which they are attached is in the closed position. A permanent magnet is enclosed in one of the mouldings and a magnetic reed switch is mounted in the other. Proximity switches normally have a sensing range of between 10mm and 15mm and they are ideal for use in a range of basic security applications.

Code

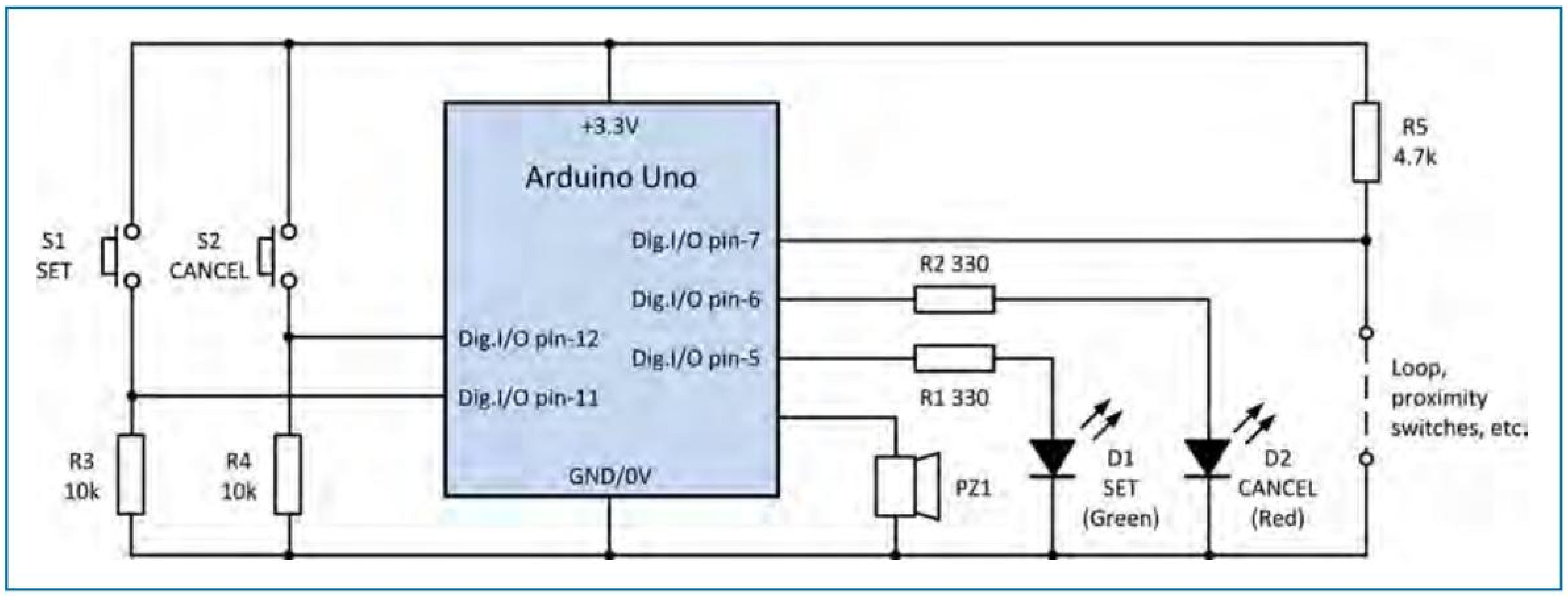
Listing 2.3 shows the complete code for the simple Arduino-based security system. To help you understand what's going on we've included numerous comments in the code. Note that the main loop contains three `while` loops. The first of these waits for the alarm to be set (using S1). The second waits for the alarm to be triggered (when the zone loop is broken) and the third waits for the alarm to be cancelled (using S2). The two LEDs indicate as shown Table 2.3.

As before, the code should be entered using the Arduino's IDE and then saved before compiling and uploading it to the Uno, as described in last month's *Arduino Workshop*. Don't forget to save your work by clicking on 'File' and 'Save' or 'Save As…' when you finish.

Next, click on 'Sketch' and 'Verify/Compile'. Where errors occur during compilation they often arise from missing semi-colons or incorrectly matched pairs of curly brackets. Note also the use of two equality signs (==) in the conditional loop statement. The compiler will fail if you only use one of them.

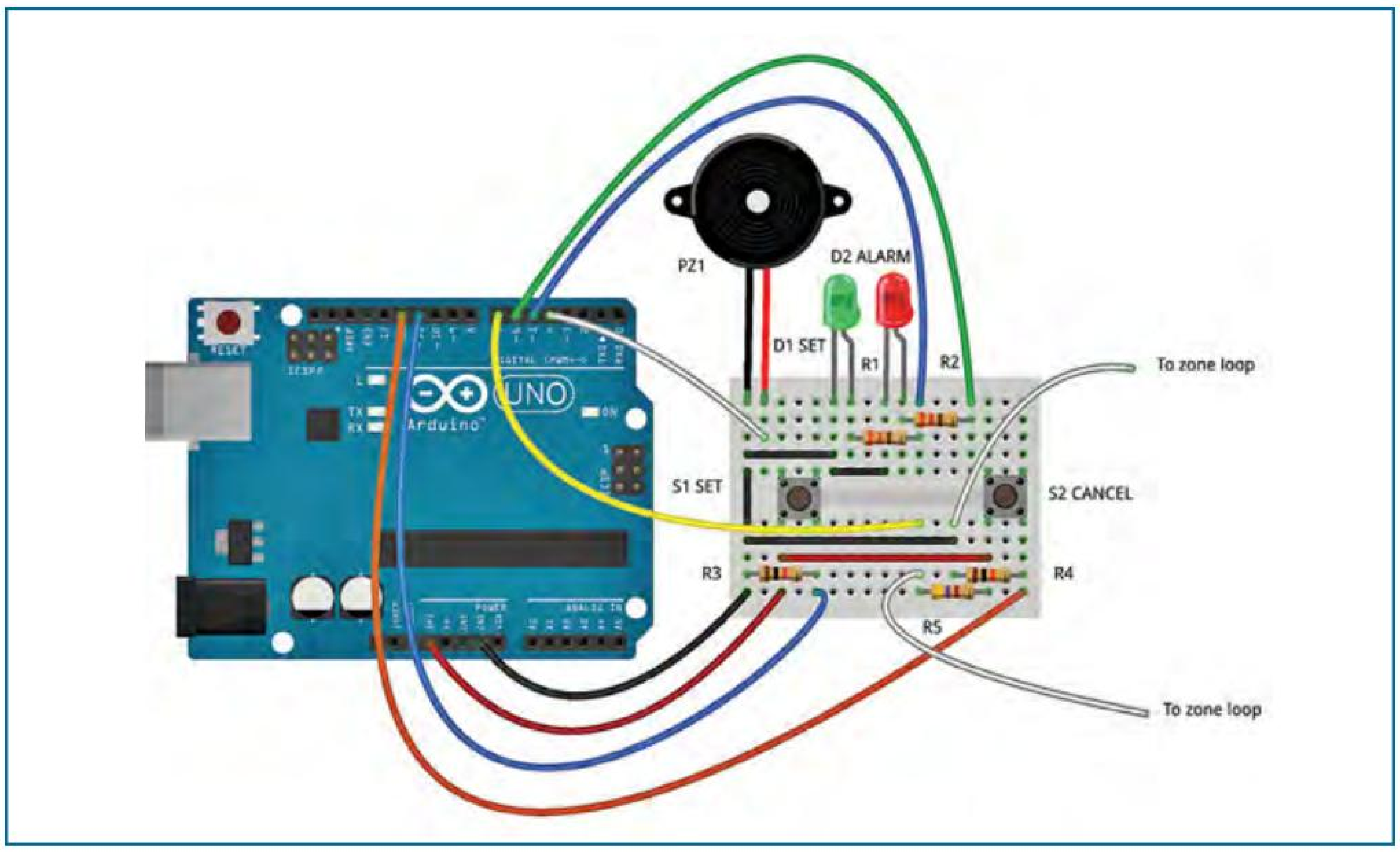
Testing

When you've corrected any coding errors that the compiler reports you will be ready to upload your code to the Uno. Just click on the upload arrow and watch



+3.3V
Arduino Uno
S1 SET
S2 CANCEL
Dig.I/O pin-7
Dig.I/O pin-6
Dig.I/O pin-12
Dig.I/O pin-5
Dig.I/O pin-11
GND/0V
R5 4.7k
R2 330
R1 330
Loop, proximity switches, etc.
R3 10k
R4 10k
PZ1
D1 SET (Green)
D2 CANCEL (Red)

Fig.2.12. Circuit of the simple Arduino-based security system



PZ1
D2 ALARM
D1 SET
R1
R2
To zone loop
S1 SET
S2 CANCEL
R3
R4
R5
To zone loop
UNO
Arduino

Fig.2.13. Fritzing breadboard arrangement for Fig.2.12

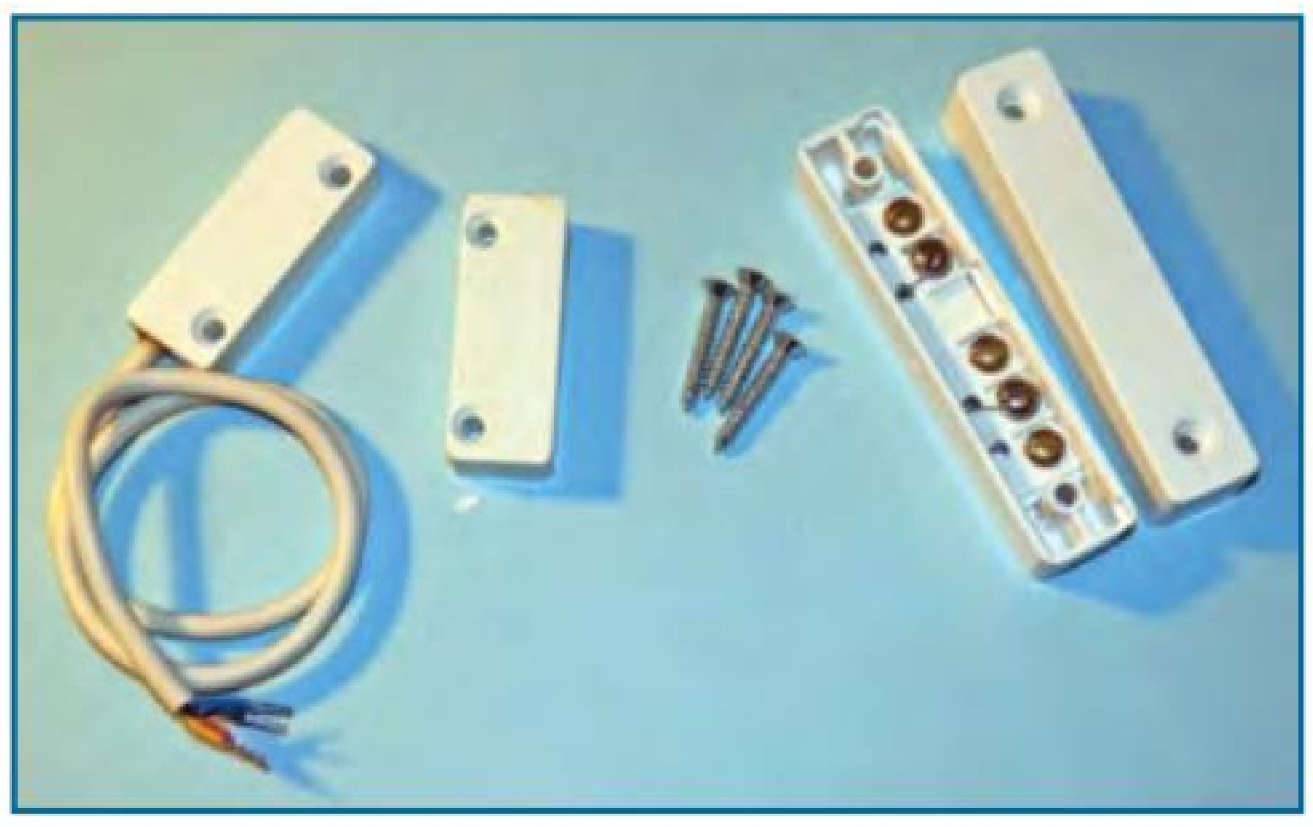
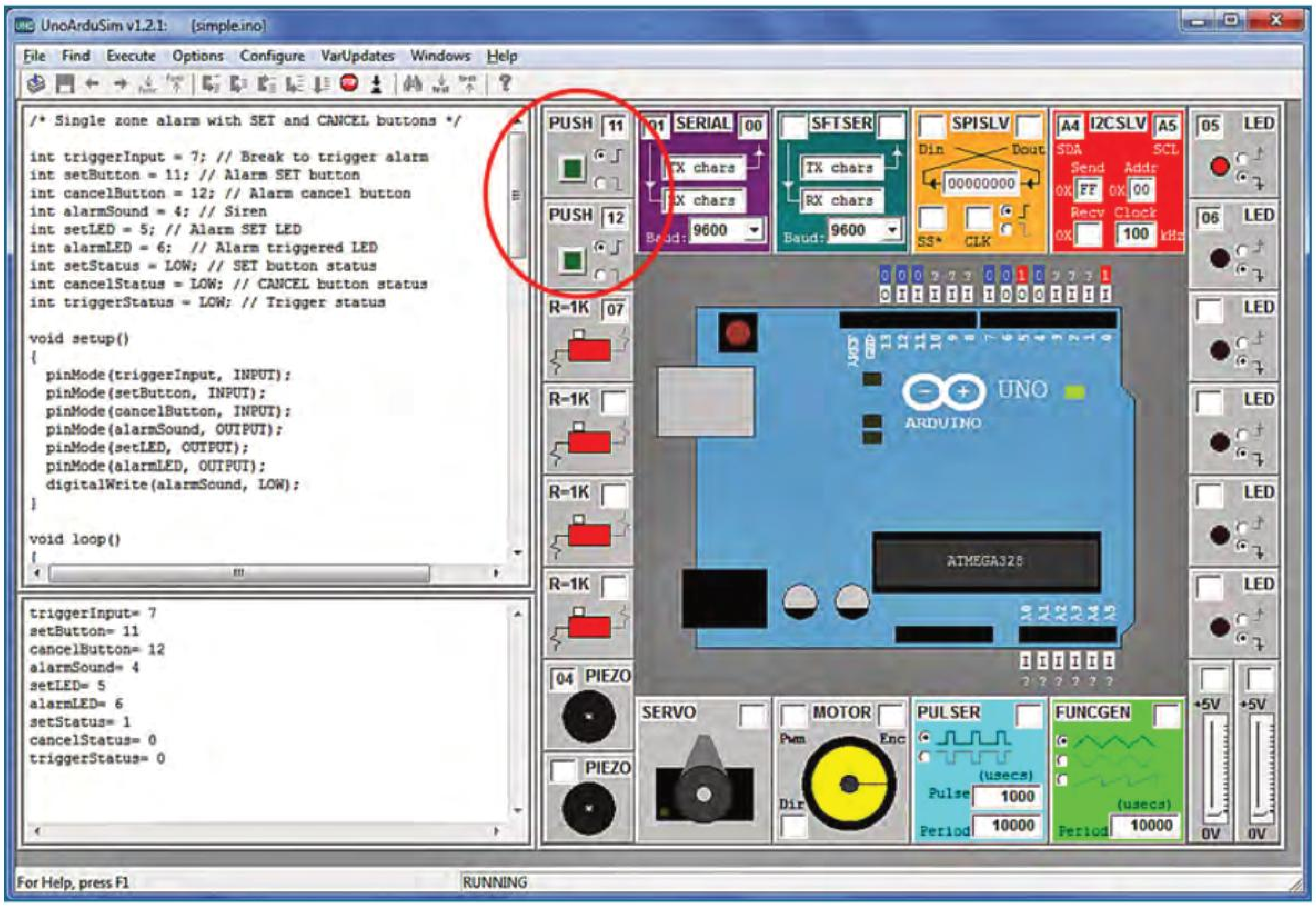


Fig.2.15. Some common types of proximity switch



```
/* Single zone alarm with SET and CANCEL buttons */

int triggerInput = 7; // Break to trigger alarm
int setButton = 11; // Alarm SET button
int cancelButton = 12; // Alarm cancel button
int alarmSound = 4; // Siren
int setLED = 5; // Alarm SET LED
int alarmLED = 6;  // Alarm triggered LED
int setStatus = LOW; // SET button status
int cancelStatus = LOW; // CANCEL button status
int triggerStatus = LOW; // Trigger status

void setup()
{
  pinMode(triggerInput, INPUT);
  pinMode(setButton, INPUT);
  pinMode(cancelButton, INPUT);
  pinMode(alarmSound, OUTPUT);
  pinMode(setLED, OUTPUT);
  pinMode(alarmLED, OUTPUT);
  digitalWrite(alarmSound, LOW);
}

void loop()
{
```

```
triggerInput= 7
setButton= 11
cancelButton= 12
alarmSound= 4
setLED= 5
alarmLED= 6
setStatus= 1
cancelStatus= 0
triggerStatus= 0
```

For Help, press F1   RUNNING

Fig.2.16. Using UnoArduSim to simulate the execution of Listing 2.3 (note that we've selected rising-edge triggering for digital inputs 11 and 12)

the progress report – but, before you do this it is important to make sure that the input loop is closed. The LEDs on the Uno should flash and the code should begin to execute. At this point neither of the status indicators, D1 and D2, should become illuminated. If you now press the SET button the green LED, D1, should become lit. This indicates that the alarm has been SET.

If you now break the loop the alarm will be triggered. In this condition the red status LED should be illuminated and the piezoelectric sounder should be operating. To reset the alarm you can press the CANCEL button, S2. Note that the alarm cannot be cancelled if the loop is still broken. To re-instate the alarm you will need to close the loop again, press the CANCEL button and, if all is well the red LED will go out and the circuit will then be ready to be put back into the SET state.

Going further

There's a great deal of scope for going further with our simple Arduino-based security alarm. The most obvious enhancement would be the addition of several more zones, each with an LED to indicate which of the zones has been triggered. All this needs is more of the digital I/O lines configured as inputs and outputs (one pair for each additional zone) together with some code that will poll each of the loops in turn to see if any of them have been triggered.

Another useful modification would be an entry/exit delay that would operate on the zone associated with access. This would allow an entry door to be opened and closed without triggering the alarm for a short period after pressing the SET button.

For applications in which a mains-operated sounder or floodlighting is to be controlled, the output from the piezoelectric sounder can be connected to a relay interface or a ready-made relay board like those described earlier in this month's *Teach In 2016*. All of this makes this simple project an excellent candidate for further experimentation.

Next month

In next month's *Teach-In 2016* we will look at displays and keyboards that can be used with the Arduino. To this end, *Arduino Workshop* deals with interfacing an alphanumeric LCD display and *Arduino World* looks at keypads and buttons. Our programming feature, *Coding Quickstart*, introduces string and string manipulation and the functions that you will need to read and print lines of text. Finally, *Get Real* will show you how to build a simple entry/access control system.

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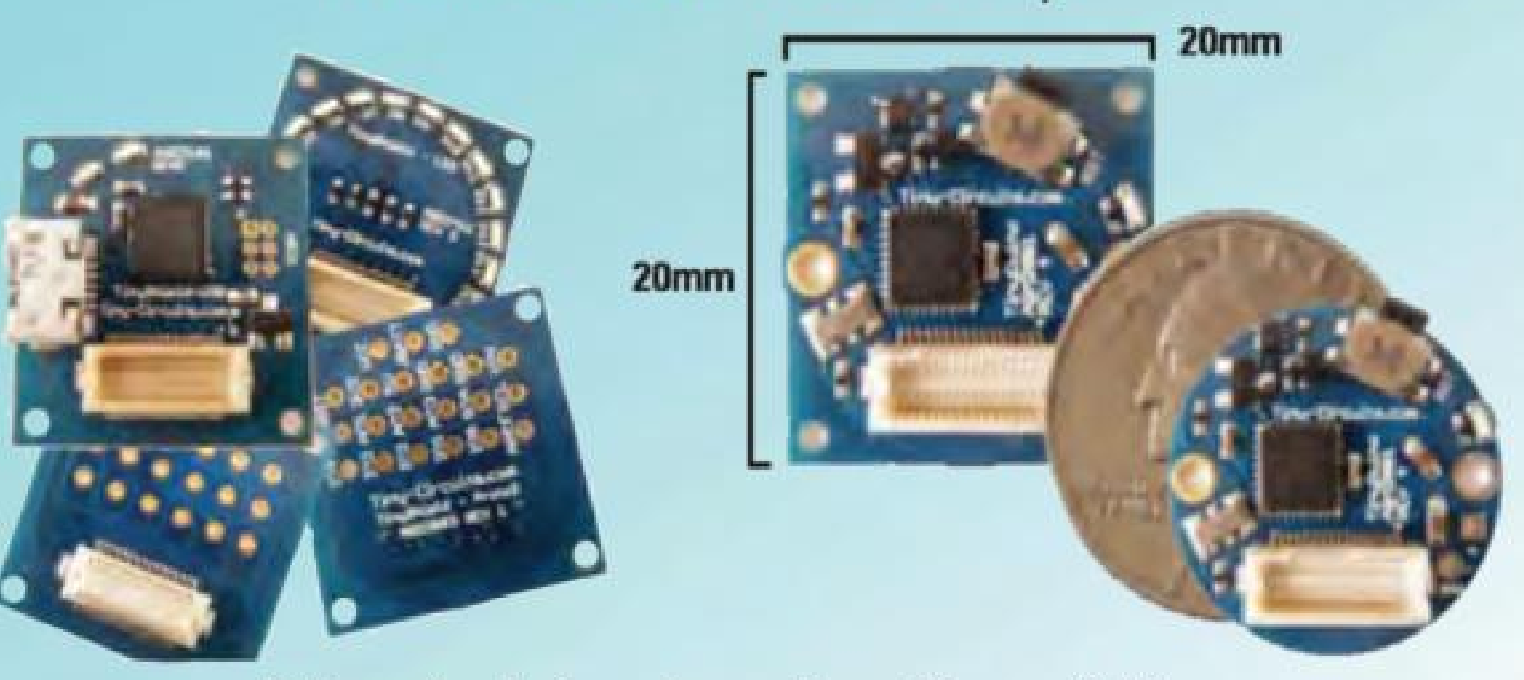

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Vz=27.74V @ 15mA
Slope R=53Ω
Zener diode analyser
Zener Voltage
Slope Resistance
Selectable Test Currents
Vz<50V
on - test
scroll - off
warning not for in-circuit

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- **Measure the true impedance of speakers and more.**
- **Great for hobbyists and professionals.**

LCR and impedance meter
Mag/Phase 200kHz
157.2Ω +80.6°
PEAK electronic design
LCR45
on - menu
enter - off
Component Summary
Inductor 23.6Ω
L=123.4μH 200kHz
Complex Impedance
Impedance 200kHz
+25.6 +j155.1Ω

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£75.00+VAT

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model DCA55
PEAK electronic design ltd
PNP Darlington Transistor
semiconductor component analyser
automatic lead identification
scroll - off
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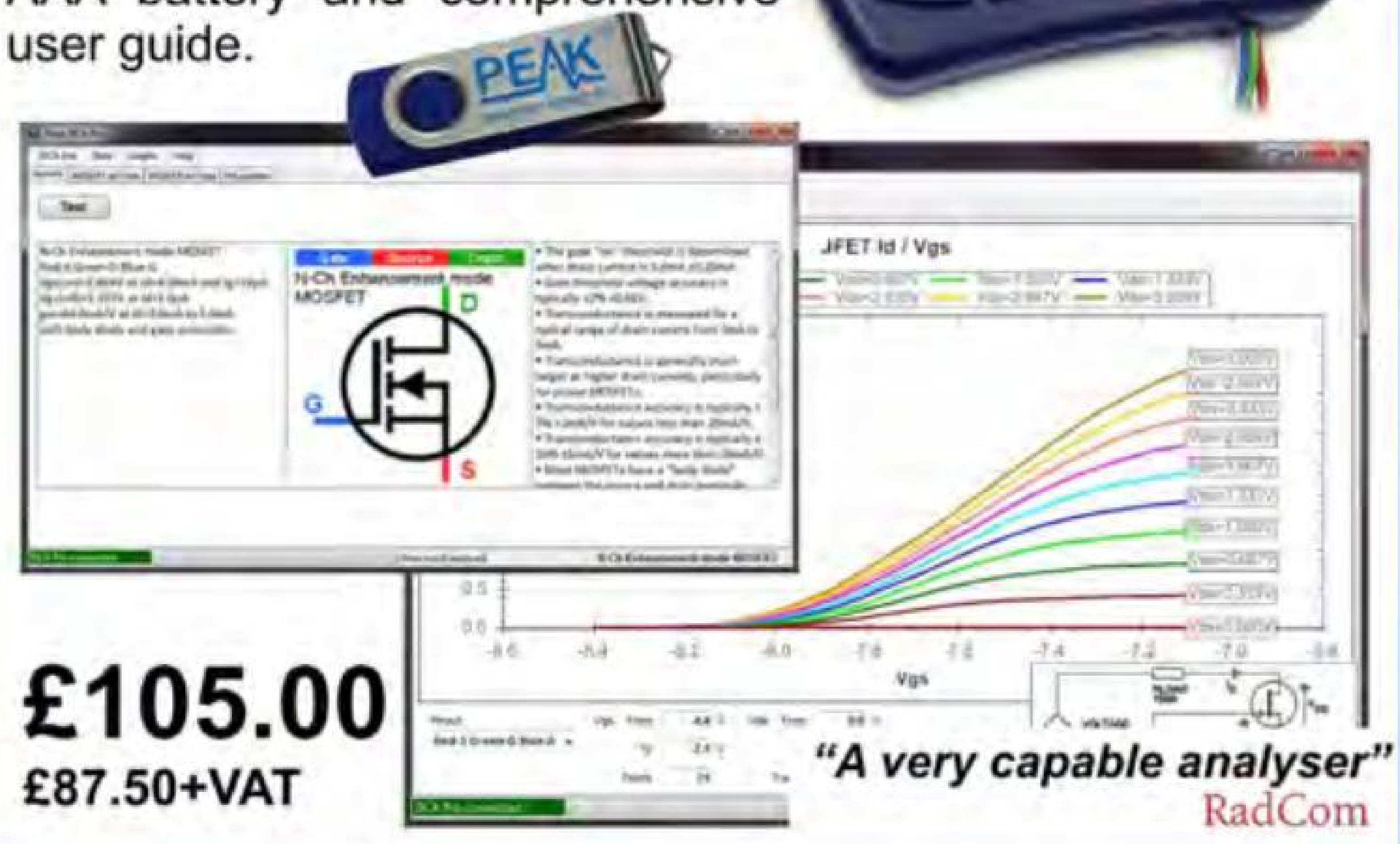
atlas DCA Pro
DCA75
USB + Graphics
PEAK


PEAK
N-Ch Enhancement mode MOSFET
D
G
S
JFET Id / Vgs
Vgs

£105.00
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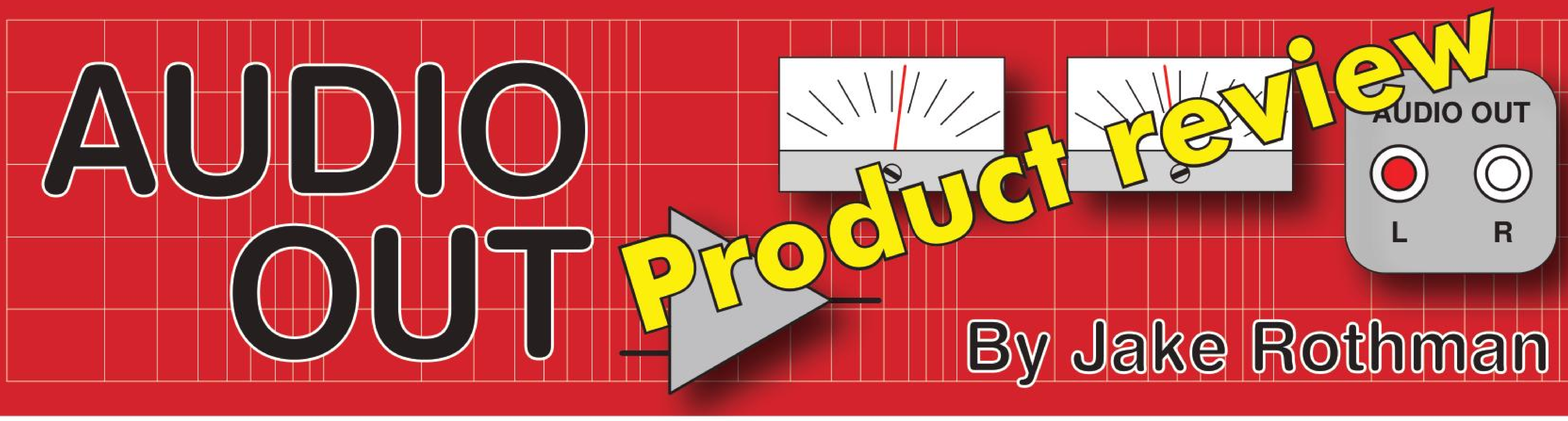
AUDIO OUT
Product review
AUDIO OUT
L
R
By Jake Rothman

Audio Out special – review of Peak LCR45

Most of us have a DMM that can accurately measure resistance – but what about capacitance, inductance and impedance? Jake Rothman reviews a flexible new impedance meter from Peak that meets this need.

Occasionally new test gear is launched that can really make one's life more productive. Sadly, often the opposite's the case, *but* the arrival of the Peak LCR45 (Fig.1) wiped many tedious and repetitive calculations from my life with the push of two little buttons. They've done the number crunching so I – and of course you – don't have to. I've always thought that being able to easily measure parameters brings the quantitative and empirical aspects of design closer together. Peak's little unit combines standard inductance (*L*) capacitance (*C*) resistance (*R*) and impedance (*Z*) measurements in a pocket-sized device.

Basic accuracy

I have a stash of military resistors and capacitors with very close 0.05% and 0.01% tolerances, see Fig.2. Checking these with the Peak showed them to read within these tolerances, which gave me confidence in the unit's basic accuracy. It was much better than my digital multimeters. The resistance agreed with my 5-digit DMM. The best inductors I have were only ±2%, but I know that Peak have 'Repair and Calibration Ltd' traceable calibration standards. The unit can even auto-null the *LRC* parameters of its own probes for accurate reading of low values.

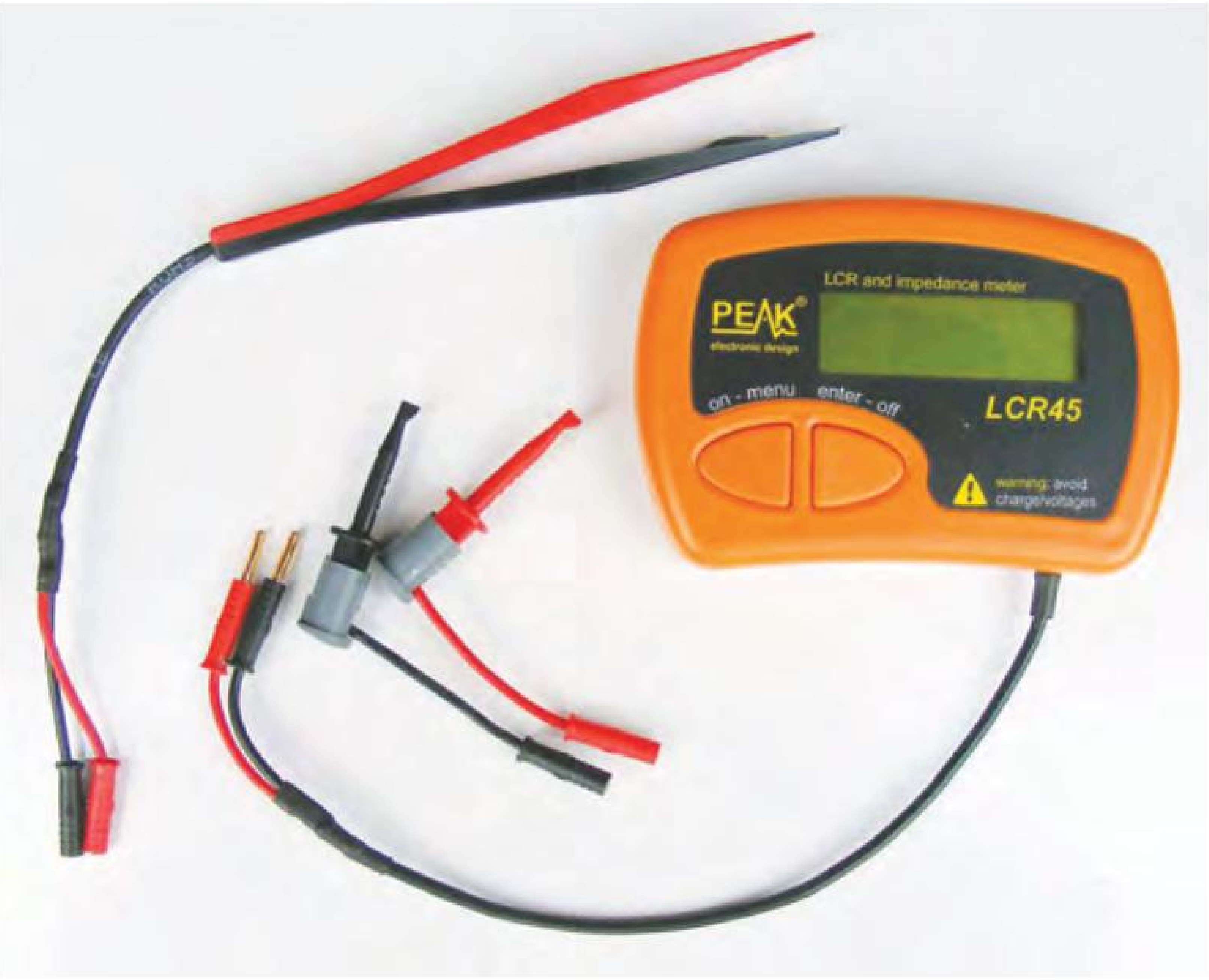
Fig.1. The LCR45 impedance analyser and LCR meter. The attachable surface-mount tweezers are an optional extra

PEAK
electronic design
LCR and impedance meter
on - menu
enter - off
LCR45
warning: avoid charge/voltages

Autosetting

The LCR45 automatically detects the type of component being measured (*L*, *C* or *R*), using DC for resistors and a suitable frequency for reactive components (1kHz, 15kHz or 200kHz). Small values need high frequencies and audio parts normally use 1kHz. It is possible to de-select the auto function and make the unit stay in one mode. For audio work, mainly transformer testing, I set it to the 1kHz inductance mode. To be honest, it is a pig for a non-menu-oriented person to set this up, possibly because of a time-out set for a 20 year-old! (My 17 year-old son can reconfigure it very quickly) I took the lazy way out and now have two units in the lab, one on auto, the other set to '*L*' at 1kHz. Maybe an extra frequency select button is the solution, but the re-tooling cost would be prohibitive.

Impedance

For beginners, I say 'impedance is AC resistance', but that is not really true. It is more accurate to say it is the Pythagorean combination of DC resistance (the real part) and AC reactance (the complex or 'imaginary'

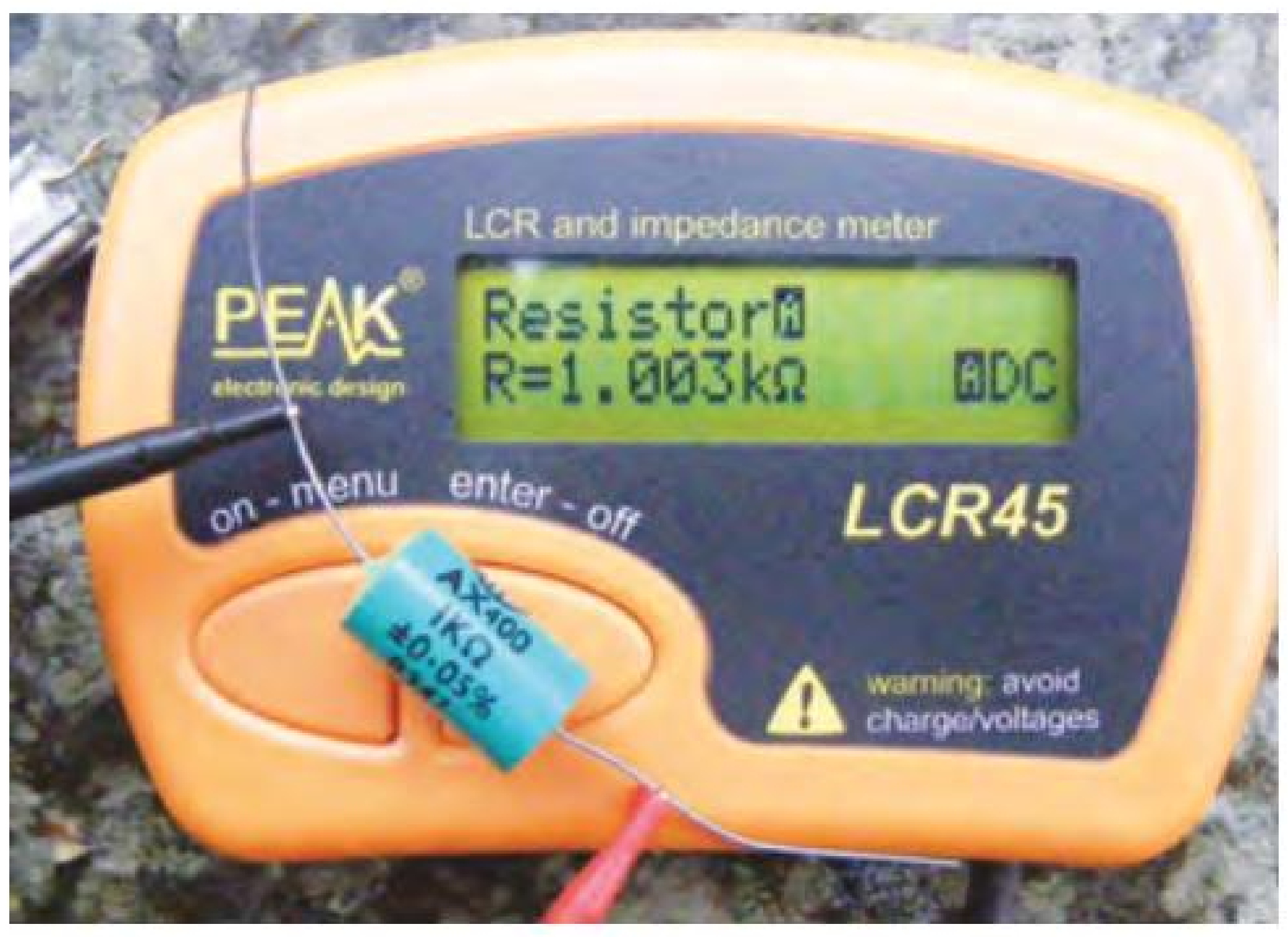
PEAK
electronic design
LCR and impedance meter
Resistor
R=1.003kΩ
DC
on - menu
enter - off
LCR45
AX100
1KΩ
±0.05%
warning: avoid charge/voltages

Fig.2. A simple task – measuring a 0.05% tolerance precision resistor

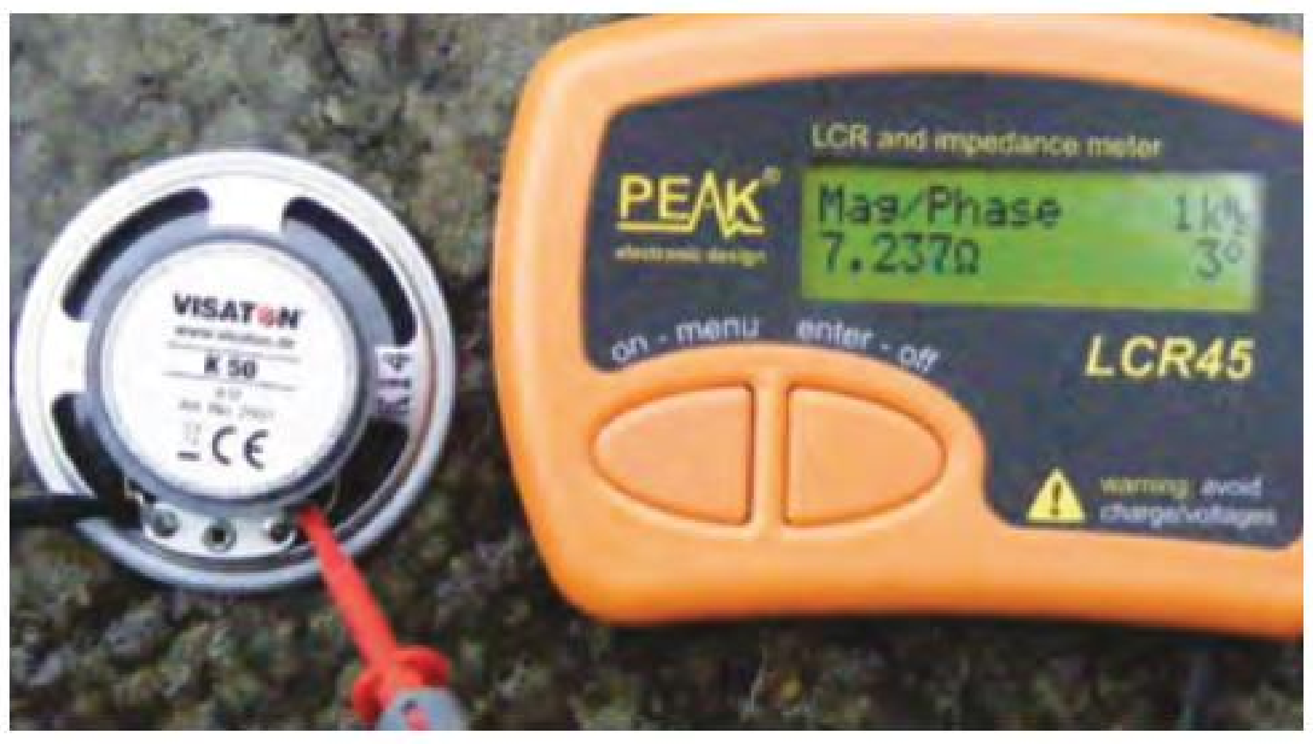
PEAK
electronic design
LCR and impedance meter
Mag/Phase
7.237Ω
1k
3°
on - menu
enter - off
LCR45
VISATON
warning: avoid charge/voltages

Fig.3. Using the LCR45 to measure the impedance of a loudspeaker. Note it is slightly below the specified 8Ω. This is a standard trick to boost the apparent sensitivity at the expense of increased current draw

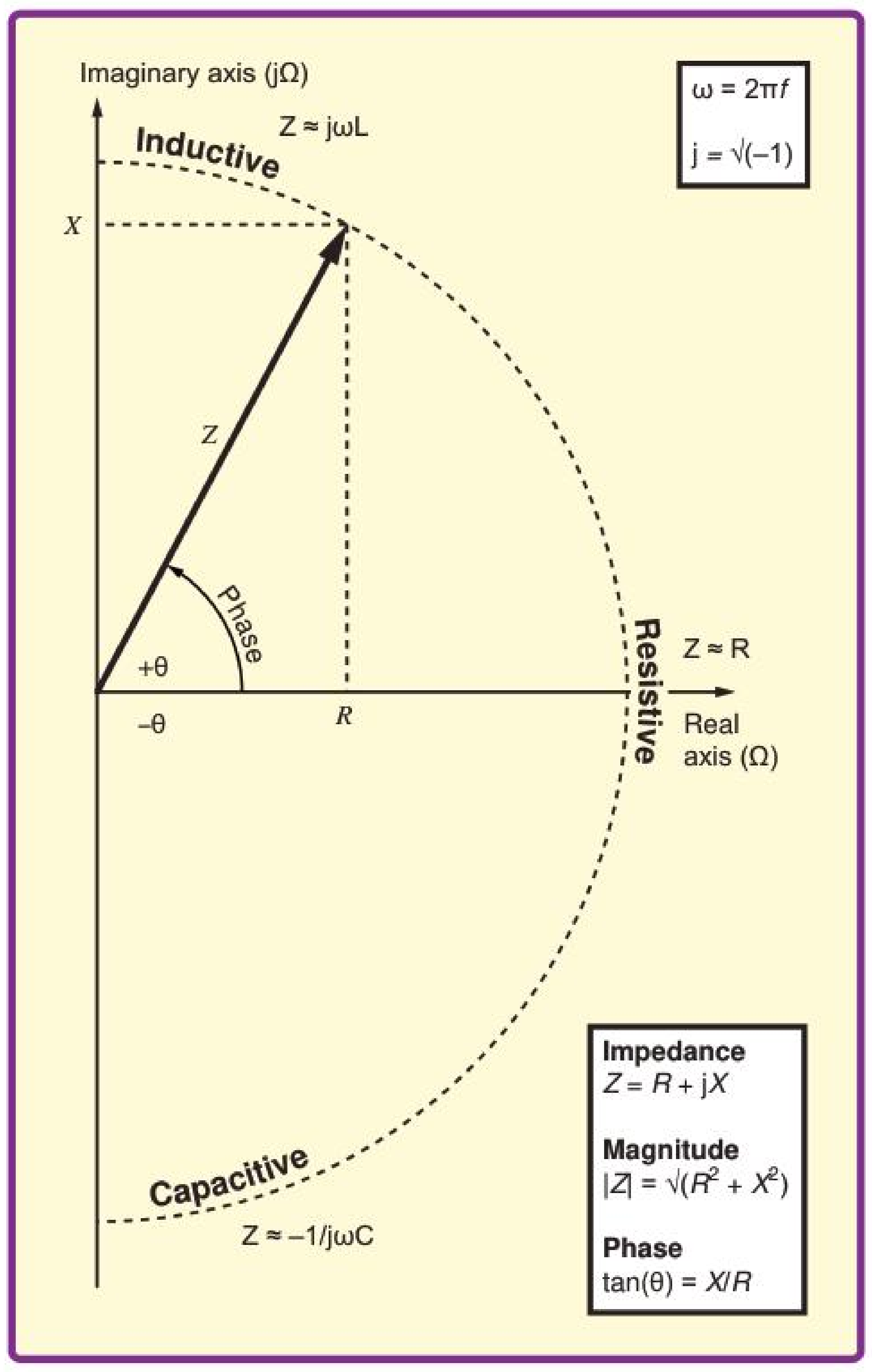
Imaginary axis (jΩ)
ω = 2πf
j = √(–1)
Z ≈ jωL
Inductive
X
Z
Phase
+θ
–θ
R
Resistive
Z ≈ R
Real axis (Ω)
Capacitive
Z ≈ –1/jωC
Impedance
Z = R + jX
Magnitude
|Z| = √(R² + X²)
Phase
tan(θ) = X/R

Fig.4. Argand diagram illustrating complex impedance

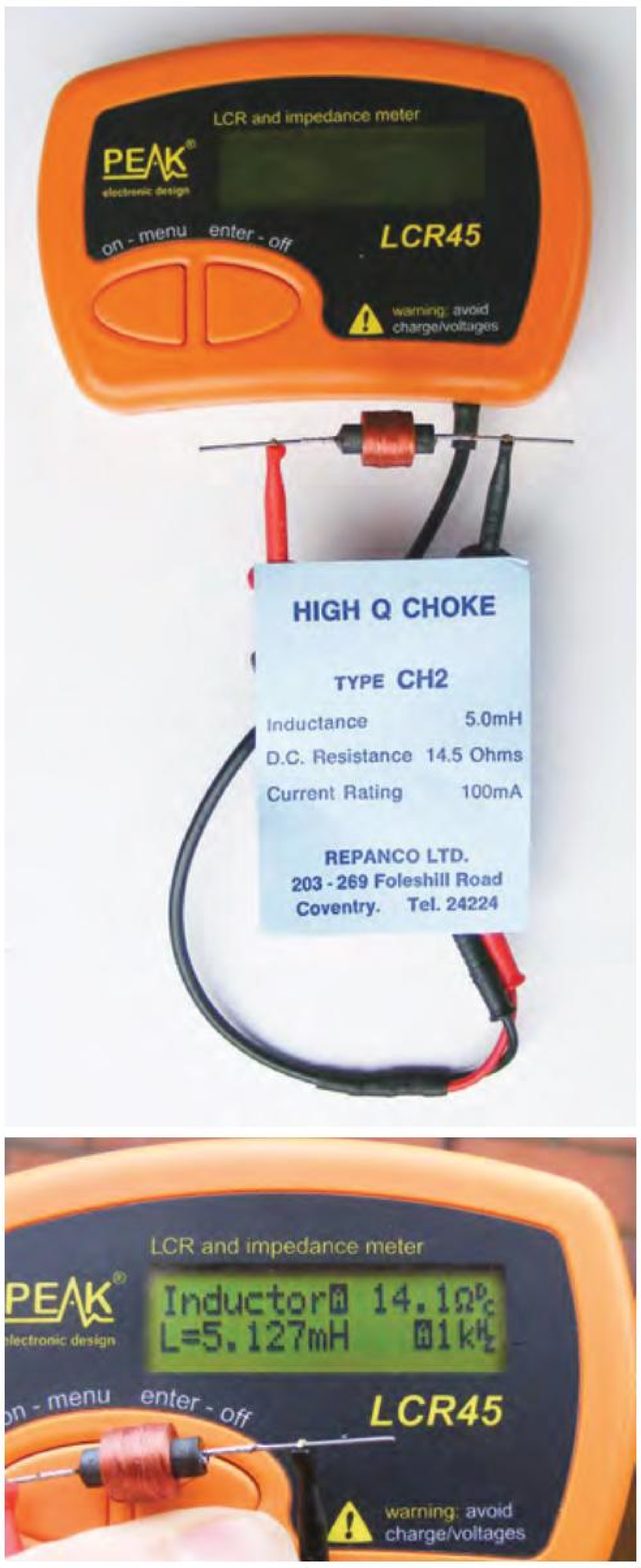
LCR and impedance meter
PEAK electronic design
on - menu
enter - off
LCR45
warning: avoid charge/voltages
HIGH Q CHOKE
TYPE CH2
Inductance 5.0mH
D.C. Resistance 14.5 Ohms
Current Rating 100mA
REPANCO LTD.
203 - 269 Foleshill Road
Coventry. Tel. 24224
Inductor 14.1Ω DC
L=5.127mH 1kHz

Fig.5a (top). Connecting a small radio frequency choke to the LCR45. Just before turn-on. Fig.5b. (bottom) Stepping through the measurement sequence on automatic with a small inductor. This shows the inductance, the DC resistance and the frequency at which the measurement was made

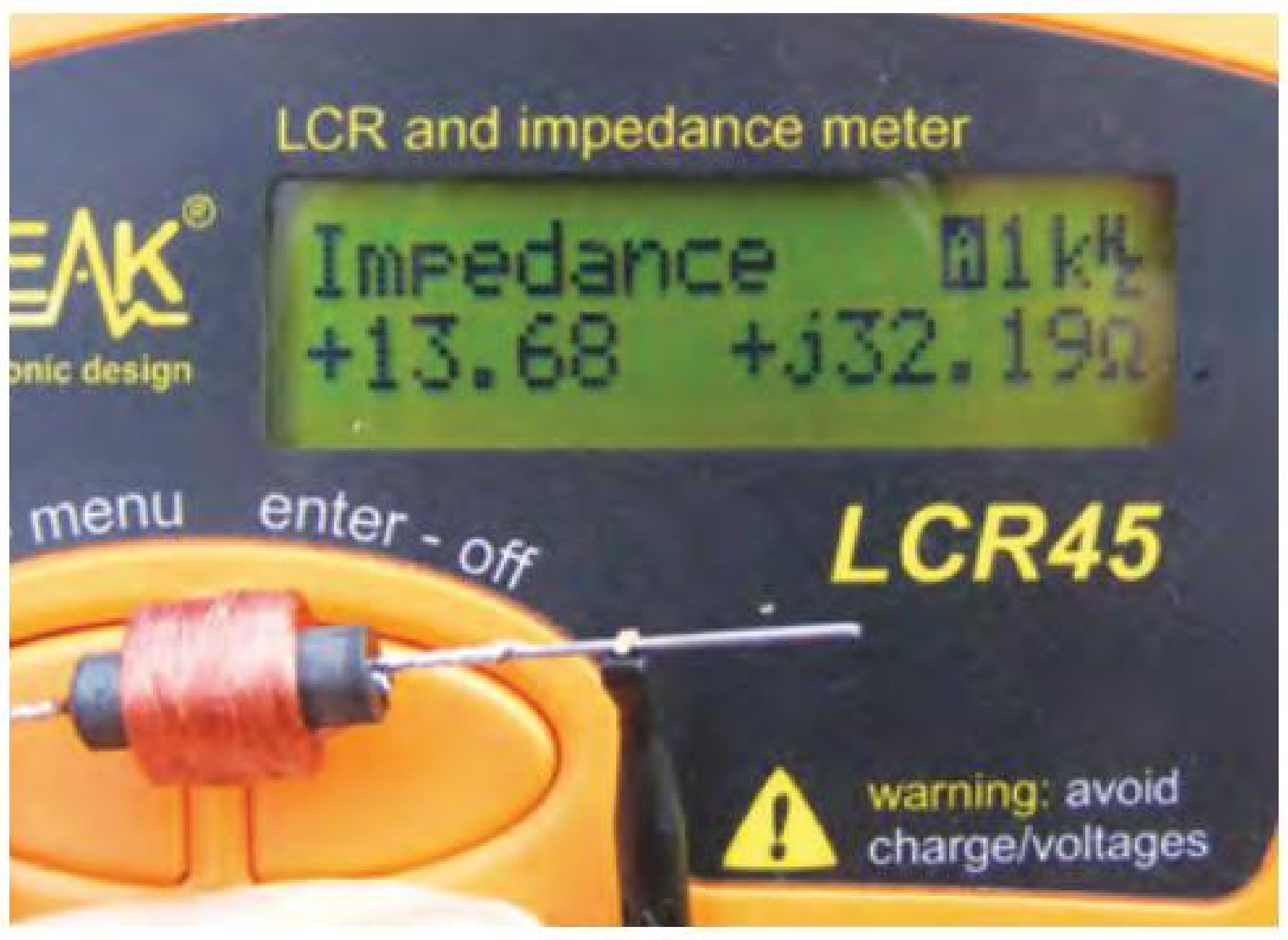
LCR and impedance meter
Impedance 1kHz
+13.68 +j32.19Ω
menu
enter - off
LCR45
warning: avoid charge/voltages

Fig.6. With each push of the 'enter' button, the unit goes onto the next measurement. Complex impedance is now displayed

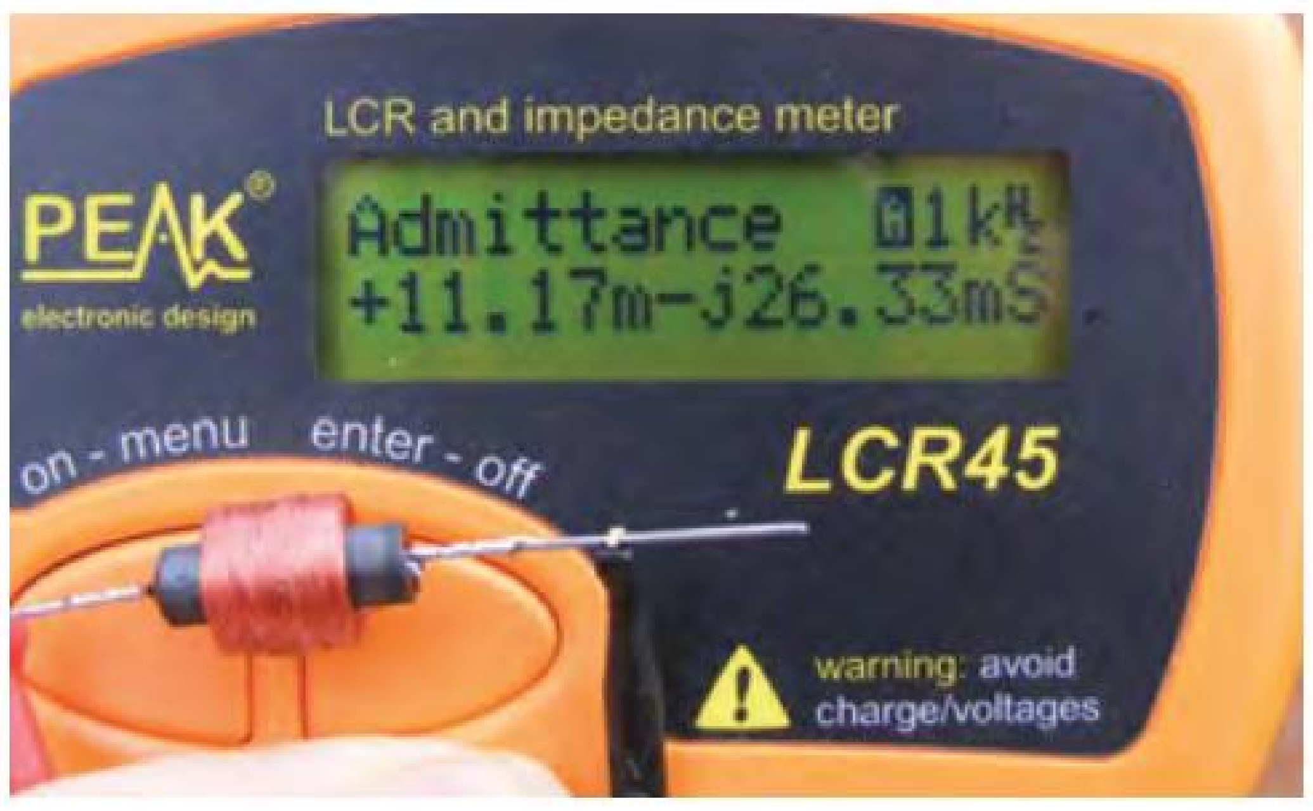
LCR and impedance meter
PEAK electronic design
Admittance 1kHz
+11.17m-j26.33mS
on - menu
enter - off
LCR45
warning: avoid charge/voltages

Fig.7. Admittance – reciprocal of impedance

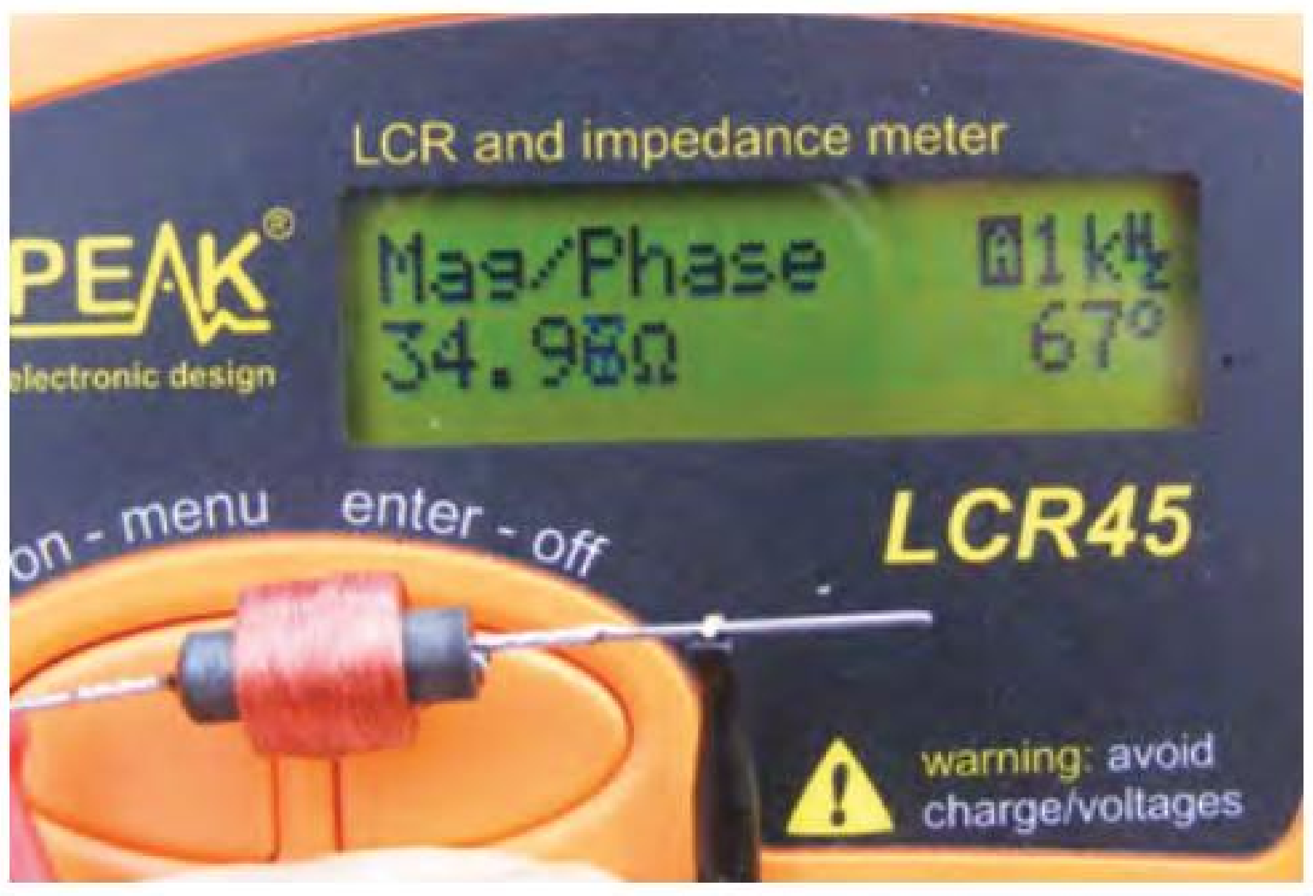
LCR and impedance meter
PEAK electronic design
Mag/Phase 1kHz
34.98Ω 67°
on - menu
enter - off
LCR45
warning: avoid charge/voltages

Fig.8. Impedance magnitude and phase

part) called the impedance magnitude. This is why some components, such as loudspeakers, are given an impedance value. A typical 8Ω speaker will have say, 6.3Ω of DC resistance due to the thin wire used in the voice coil and an inductance due to the winding on a magnetic core. Fig.3 shows a small Visaton 8Ω speaker measured on the Peak. Note that the impedance's magnitude and the phase are given. This is called 'polar form'. Speaker impedance is normally specified at 1kHz in the middle of the audio range and well away from the fundamental resonance, which causes an impedance peak.

Complex numbers

When dealing with impedances and reactances, pretty soon you bump into an area of mathematics called 'complex numbers'. An equipment review isn't the place for a maths lesson, but it is well worth explaining why they are used. If you are dealing with alternating voltages and currents then to fully describe a signal you need to quantify the signal's frequency and magnitude (for example its peak value). However, that is not the full picture. You also need to describe a signal's phase. For example, the phase relationship between current and voltage. In a purely resistive circuit the current and voltage are exactly in phase – the voltage and current rise and fall together; but, as soon as you add some capacitance and/or inductance then this phase relationship changes, and this is where complex numbers become useful. Applying complex numbers let's you easily take account of not just frequency and magnitude, but also phase. When wielding 'complex numbers', engineers use the *j* operator to wind up mathematicians who like to use *i* to denote 'imaginary' numbers (more seriously, *j* is used to avoid confusion with *i* for current).

When quoting an impedance (Z) in complex form you will see a figure of the form $Z = R + jX$. The R represents the purely resistive part of the impedance and the X part is the purely reactive part. You can't just add these two components together because the X part is multiplied by *j*, the complex operator. Although tricky to use, complex notation is a useful mathematical tool to indicate the reactive and real parts of an impedance. The main advantage is that we can perform AC circuit analysis using simpler calculating techniques developed for DC. To have a tester that gives a direct readout for a component or network in complex form is unique at Peak's price.

'Complex numbers' do appear complex to many electronics students and they find AC theory dull. The Peak unit's instant readout (see Fig.6) removes this layer of abstraction, aiding the learning and prototyping process. I remember the same liberation occurring when we went from null bridges to digital multimeters. (I must talk to the university technician and get him to order some!) The proper printed manual supplied with the Peak illustrates complex impedance in a succinct 'Argand diagram', shown in Fig.4. The unit will also give admittance readings (see Fig.7) which are the reciprocal of impedance and useful for calculating components in parallel.

Testing common components

Inductors

A great deal of inductors are custom-made components having only a cryptic in-house ID number and many more are simply left unmarked. An inductance meter is a great help here. Also, one may have to wind one's own for say, Theremin loading coils, lightning detectors and switch-mode power supplies. Using the Peak I was horrified to see the discrepancies between data-sheet calculations for pot cores and the actual measurements; sometimes 50% out.

Since the unit gives simultaneous readings for inductance and DC resistance, it is ideal for checking loudspeaker passive crossover inductors, which are often air-cored with significant resistance. This must be taken into account with the design. The same is true with RF (radio frequency) components where the resistive losses determine the 'quality factor' or Q of resonant circuits. Fig.5 to Fig.8 show me stepping through the readings for an old radio frequency choke.

Capacitors

The LCR45 has a null function for cancelling the probe parasitic capacitance and it is capable of measuring very low capacitances, such as those between strips in a breadboard, down to about 0.5pF. Fig.9 shows the unit measuring a close tolerance polystyrene capacitor.

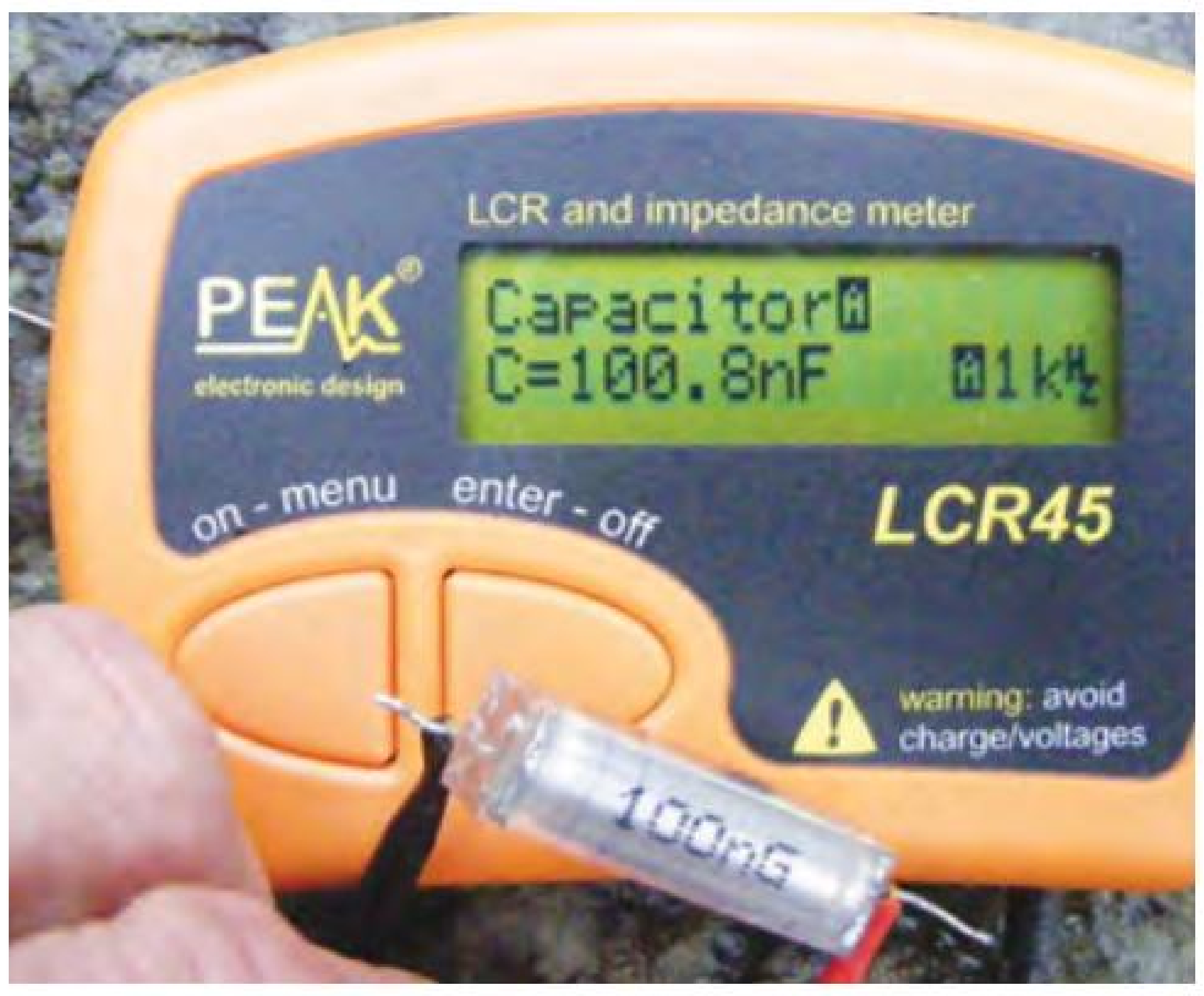
LCR and impedance meter
PEAK electronic design
Capacitor
C=100.8nF 1kHz
on - menu
enter - off
LCR45
warning: avoid charge/voltages
100nF

Fig.9. Measuring a 2% tolerance 100nF polystyrene capacitor

Resistors

One problem I have had with with wirewound resistors is parasitic inductance. The 0.22Ω source resistor shown in Fig.10 caused oscillation problems with some MOSFET power amplifiers I was designing. The inductance was 10 times higher than normal, which stopped the Zobel network from working. I found the cause to be the resistor manufacturer had used low-resistance copper wire instead of Nichrome, requiring many more turns for a given resistance. This resulted in higher inductance. A normal Welwyn vitreous wire-wound resistor is shown in Fig.11. If you need a near-zero inductance resistor then a film or composition resistor must be used (Fig.12).

Audio transformers

For anybody involved in transformer-coupled audio circuits, this tester is an essential piece of kit. For example, if you are building a Deacy amp (see *Germania* Part 3, *EPE* June 2015); a transformer-input moving-coil RIAA pre-amplifier (*EPE* Oct 2015); or a Neve microphone pre-amplifier, you can check your transformer impedances are right. I even used the unit to sort out an impedance problem with a 100V line-distributed loudspeaker system in a hotel which paid for the unit several times over. Here's some measurements I took from some common audio transformers:

- Eagle LT44 driver transformer loaded with 1kΩ across whole secondary, Z_{in} = 16.5k, primary inductance = 738mH
- LT700 output transformer with 3.3Ω load, Z_{in} = 1.1kΩ across whole primary, 38mH inductance (useful for calculating the bass roll-off point)
- LT726 output transformer with both 3.2Ω and 8Ω loads, Z_{in} = 476Ω
- Vigortronix VTX-101-003 in MC (moving coil) pre-amplifier, Z_{in} = 261Ω with 47kΩ load
- Xicon 42TU200-RC output transformer gave expected 200Ω load with 8Ω winding. I found the secondary was actually a centre-tapped (CT) winding, which gave 2Ω as the correct load for the 3.2Ω winding. The Peak uncovered a winding error here! This was no loss, as I soon developed a distributed load germanium output stage to use the CT output winding. Fig.13 shows the Xicon transformer connected to an 8Ω speaker, giving the expected 200Ω reflected load.

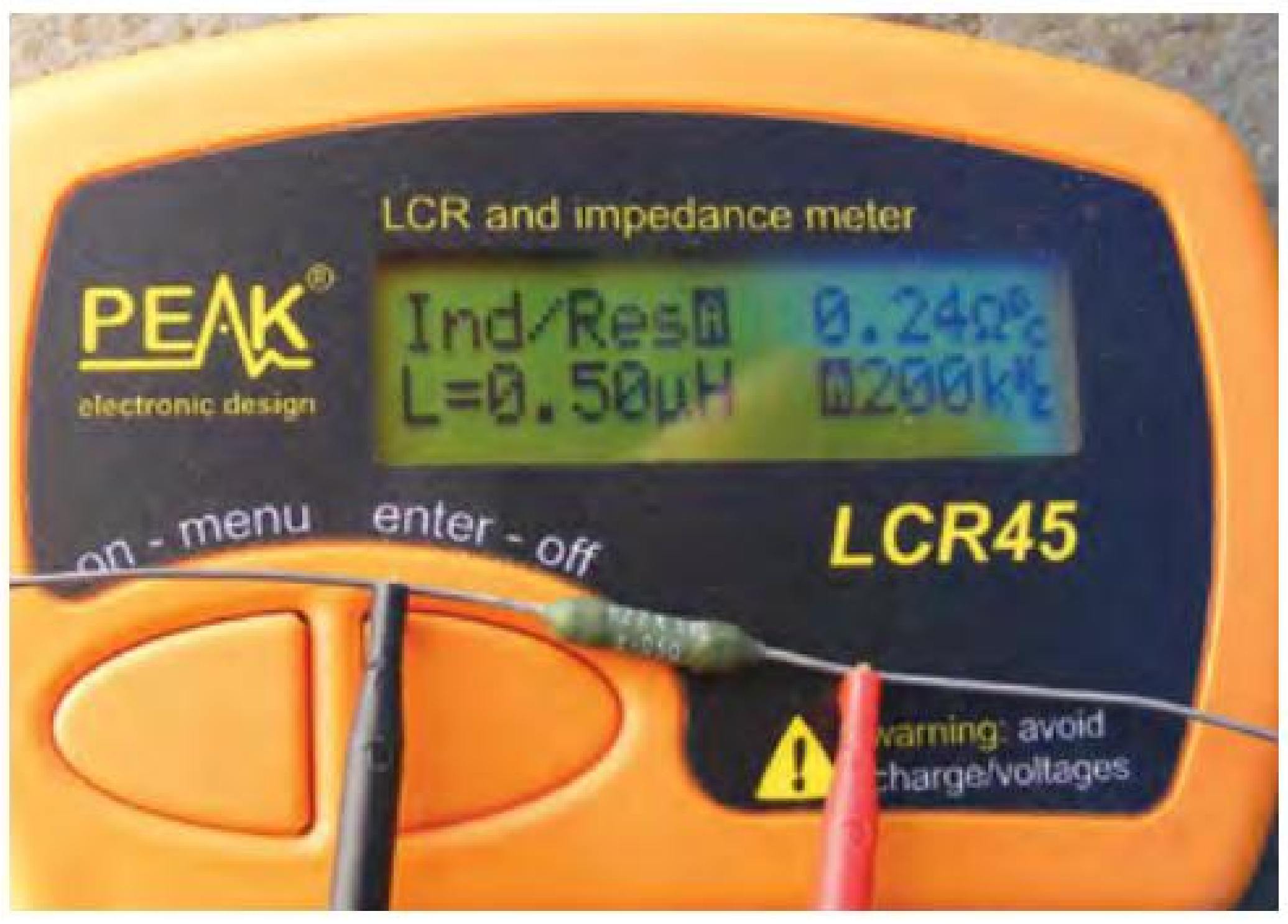
LCR and impedance meter
PEAK electronic design
Ind/Res 0.24Ω
L=0.50µH 200kHz
on - menu
enter - off
LCR45
warning: avoid charge/voltages

Fig.10. 0.22Ω wire-wound resistor with unusually high parasitic inductance. These resistors caused problems when used as source/emitter resistors in audio power amplifiers

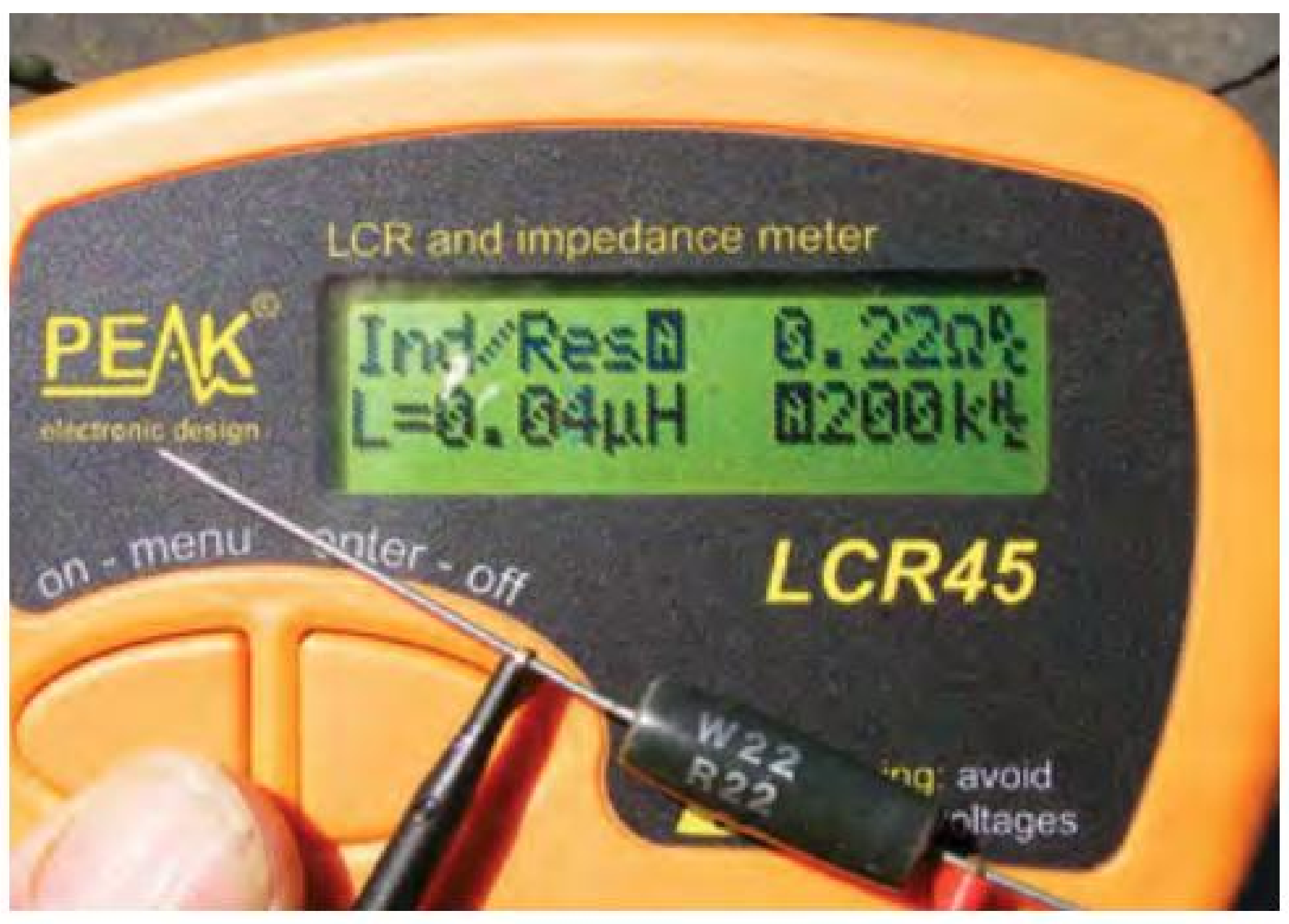
LCR and impedance meter
PEAK electronic design
Ind/Res 0.22Ω
L=0.04µH 200kHz
on - menu
enter - off
LCR45
W22
R22

Fig.11. 'Normal' wire-wound resistor inductance

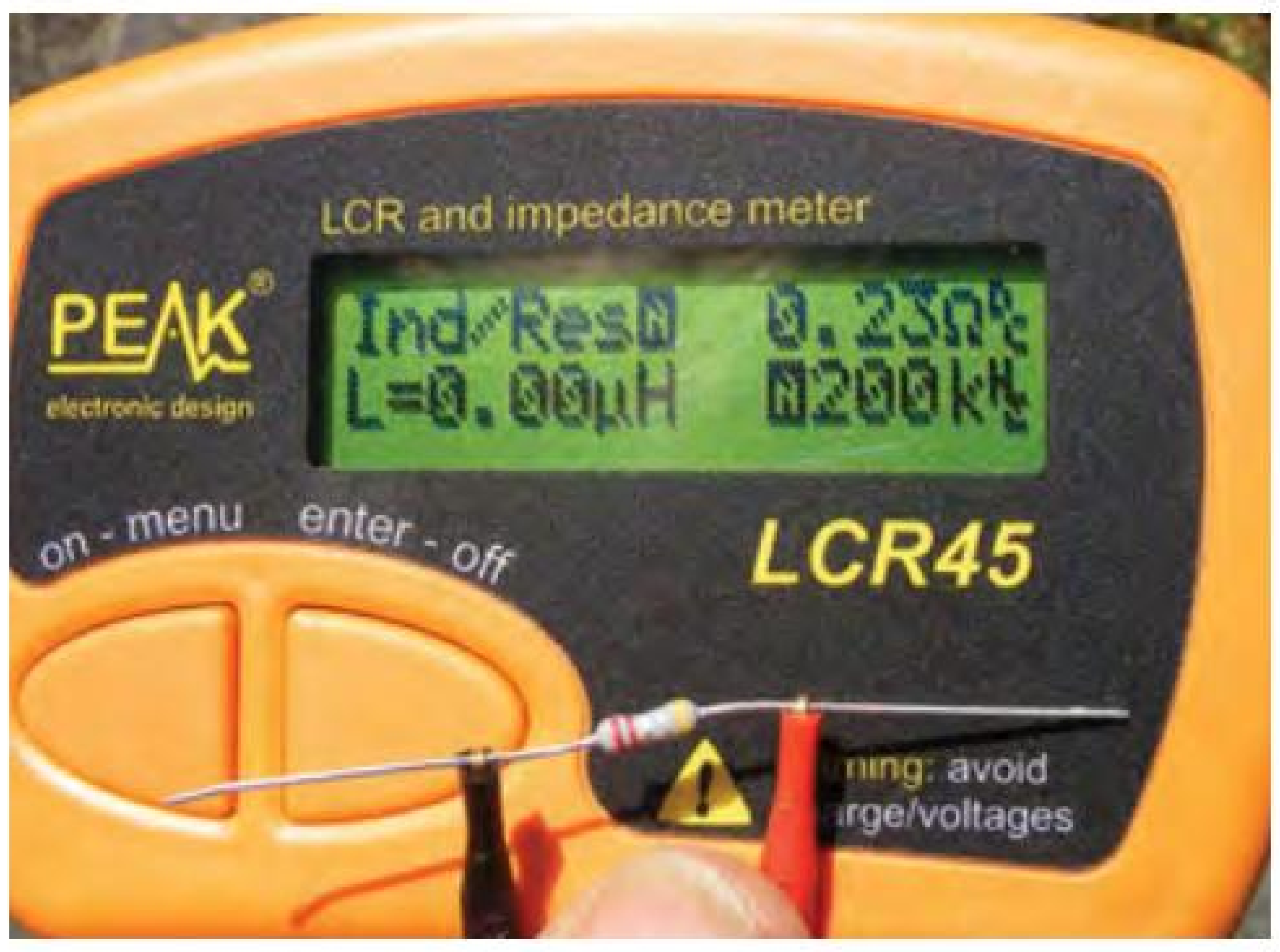
LCR and impedance meter
PEAK electronic design
Ind/Res 0.23Ω
L=0.00µH 200kHz
on - menu
enter - off
LCR45

Fig.12. A fusible metal-film resistor exhibits negligible inductance

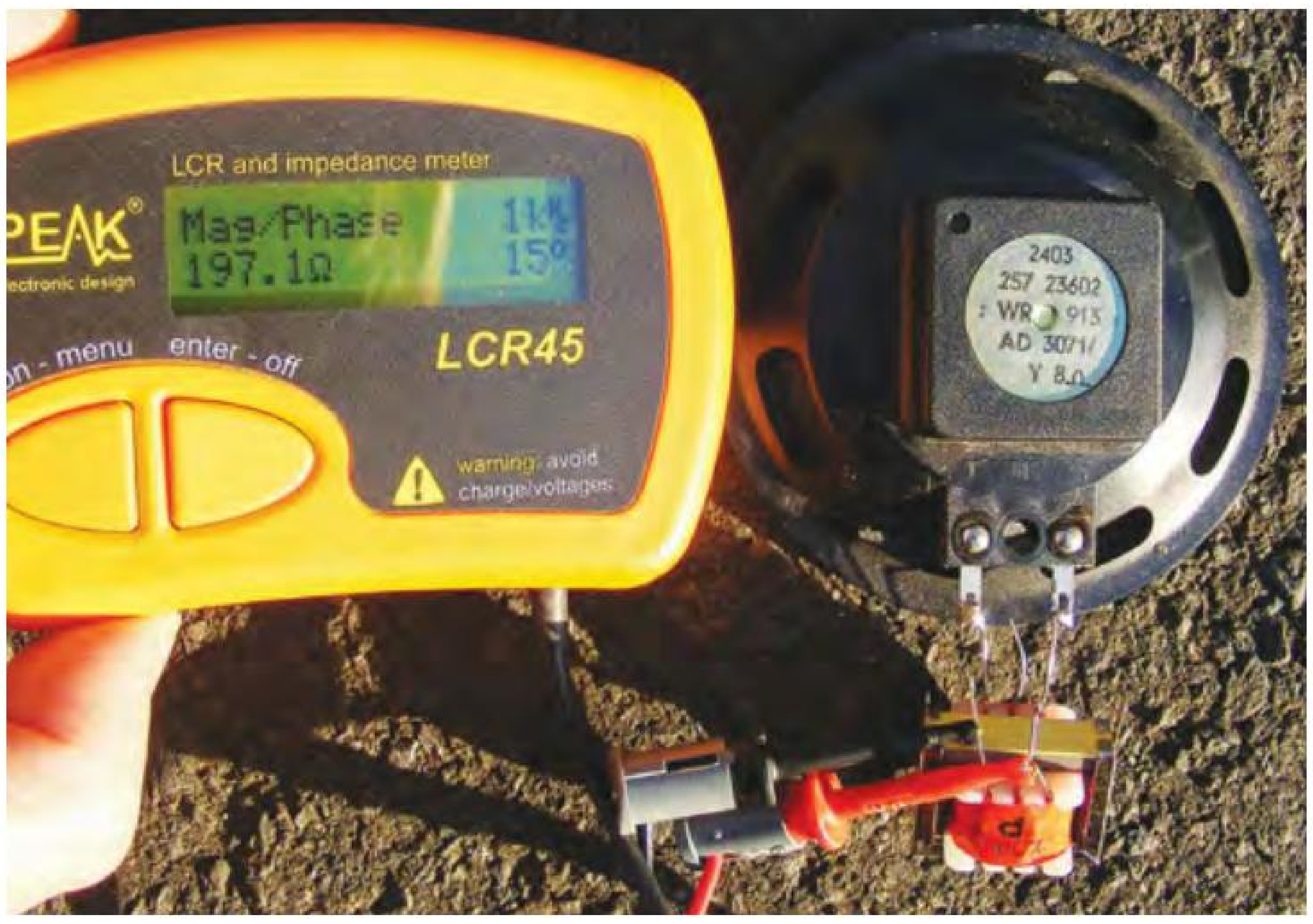
LCR and impedance meter
PEAK electronic design
Mag/Phase
197.1Ω
on - menu
enter - off
LCR45
warning: avoid charge/voltages

Fig.13. Measuring the impedance of an 8Ω speaker reflected through the Xicon output transformer. Your delicate germanium transistors will be safe

Currawong inspiration

I wish I had got round to trying cheap 100V line transformers for output transformers in a valve amp like the recent *Currawong Valve Amplifier* design (*EPE*, November 2015). Sifting through the vast number of variations produced to find the right one was a massive task I never finished. This is because the load impedances aren't specified, manufacturers usually just quote the power drawn from the line – typically 1.25W, 5W… Although it is perfectly possible to calculate the impedance knowing just the power tap and the load impedance, it is much more accurate to measure it directly. Here are the theoretical impedance values from $R = V^2/P$ where P is the power tapping and V =100V RMS:

15W	660Ω
12W	827Ω
6W	1650Ω
5W	2000Ω
4W	2500Ω
3W	3330Ω
2.5W	4000Ω
2W	5000Ω
1.5W	6500Ω
1.25W	8kΩ
1W	10kΩ
0.5W	20kΩ

100V line transformers can only be used with push-pull valve amplifiers since they cannot tolerate a DC component in the core because they are un-gapped. This means they must have a centre tap on the winding. Most of my 100V line transformers had to be instantly dismissed for valve use because the tappings were on the secondary low-impedance side. To measure the impedance on the primary it is essential to load the secondary with the specified impedance, usually an 8Ω or 16Ω resistor (see Fig.14). I had one Eagle P038 transformer which measured half the calculated impedance and whose centre tap was not quite mid-way. I finally found a 20W

C 8Ω 16Ω
modle 952.440UK
adastra

Fig.14. When measuring the impedance of transformers it is essential they are loaded with the correct load resistance

Adastra transformer that gave an 8kΩ load with a centre tap, see Fig.15. Note this measures 2kΩ each way from the centre tap because impedance ratio is turns ratio squared. This is ideal for a pair of EL84 pentode valves, beloved by guitarists for the basis of a 10W guitar amp, as shown in Fig.16. It also had a 16Ω tap on the secondary for use with light paper-cone 16Ω 12-inch Celestion G12 speakers, often cited as being an essential component of the 'British guitar sound'.

Other measurements

I measured the output impedance of my test bench amplifier (*EPE*, Dec 2014) in constant-current mode and found it was 24Ω. I calculated it to be 50Ω. (Important note – be careful when doing measurements like this, it could damage the Peak meter.) The Peak is also useful for measuring input impedance and input capacitance, often due to the Miller effect and RF filters. You need to be careful the 1.5V peak-to-peak pulsed 1kHz test signal does not cause overloading, as this will alter the reading.

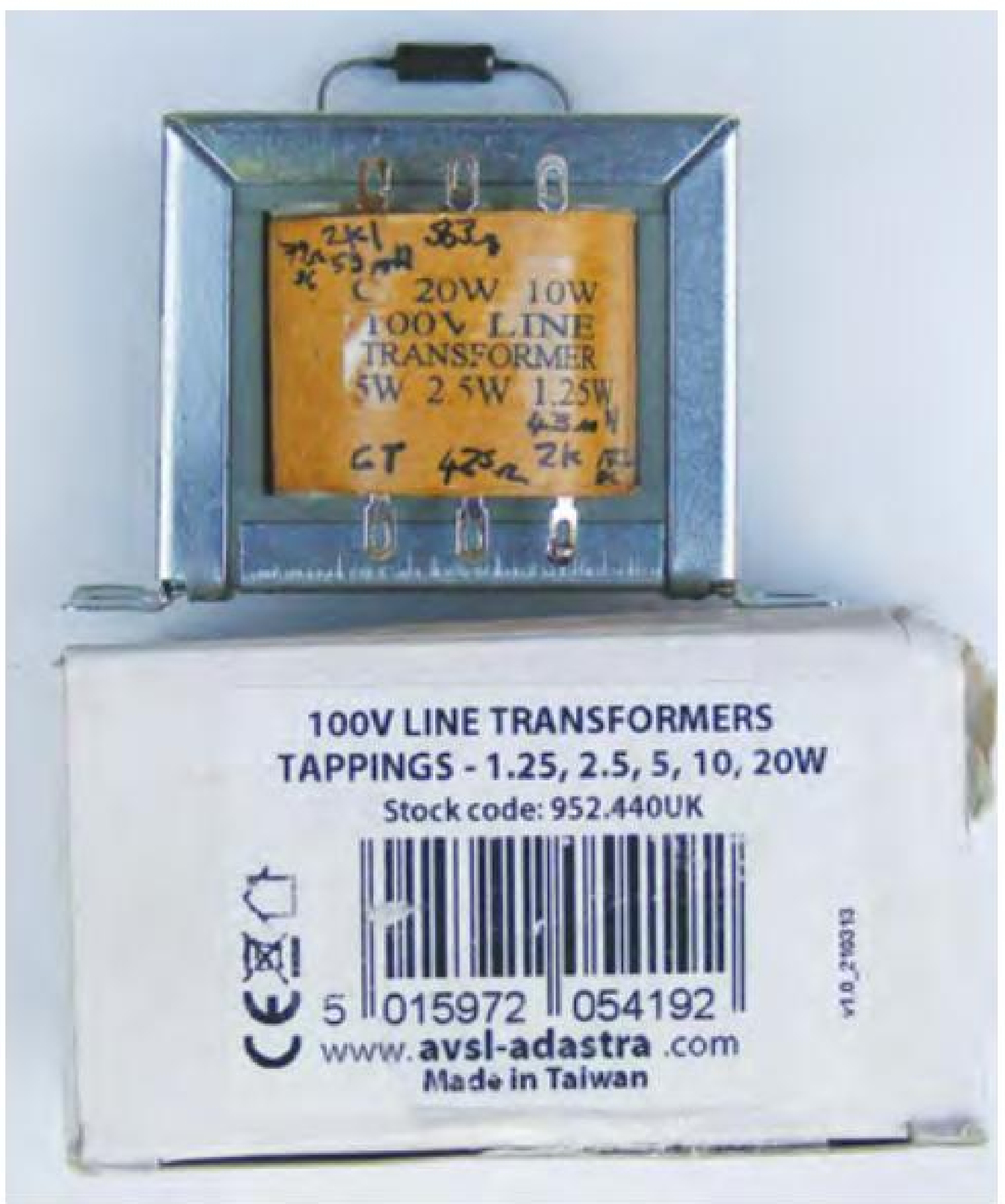
C 20W 10W
100V LINE
TRANSFORMER
5W 2.5W 1.25W
CT 425Ω 2k
100V LINE TRANSFORMERS
TAPPINGS - 1.25, 2.5, 5, 10, 20W
Stock code: 952.440UK
5 015972 054192
www.avsl-adastra.com
Made in Taiwan

Fig.15. This Adastra 20W 100V line transformer is ideal for small valve amplifiers. It gives an 8kΩ anode-to-anode load with a centre tap. Stock code 952.440UK. Order code from CPC is DP33221, £7.50 plus VAT

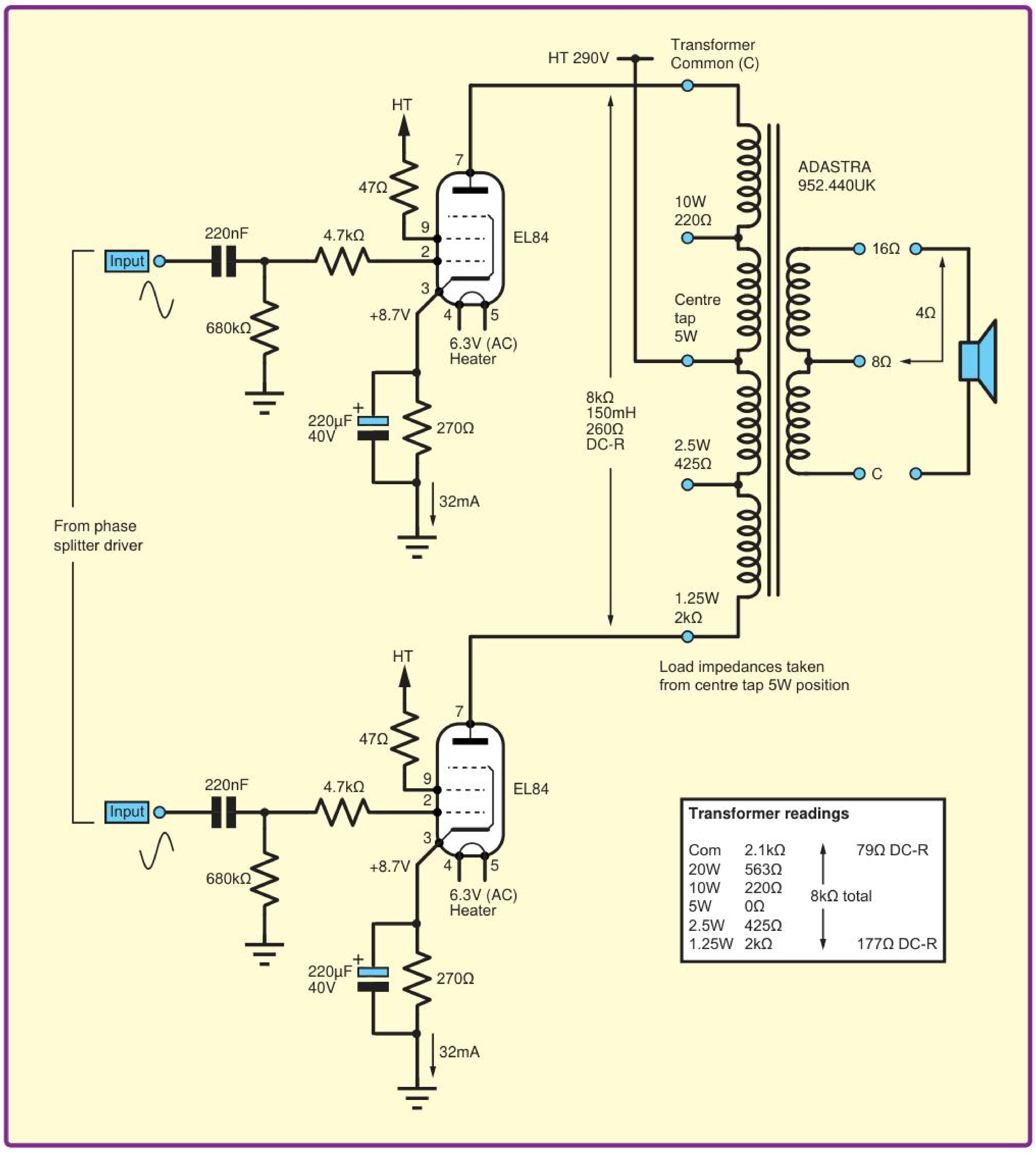
HT 290V
Transformer
Common (C)
HT
47Ω
7
9
2
3
4
5
EL84
220nF
4.7kΩ
Input
680kΩ
+8.7V
6.3V (AC)
Heater
220µF
40V
270Ω
32mA
From phase
splitter driver
10W
220Ω
Centre
tap
5W
8kΩ
150mH
260Ω
DC-R
2.5W
425Ω
1.25W
2kΩ
ADASTRA
952.440UK
16Ω
4Ω
8Ω
C
Load impedances taken
from centre tap 5W position
HT
47Ω
7
9
2
3
4
5
EL84
220nF
4.7kΩ
Input
680kΩ
+8.7V
6.3V (AC)
Heater
220µF
40V
270Ω
32mA
Transformer readings
Com 2.1kΩ
20W 563Ω
10W 220Ω
5W 0Ω
2.5W 425Ω
1.25W 2kΩ
8kΩ total
79Ω DC-R
177Ω DC-R

Fig.16. A typical valve output stage suitable for a small guitar amp using the Adastra transformer. Using 100V line transformers will save about £40.00, but you need a Peak analyser to check the impedances are right

Surface-mount tweezers

One part of my work is reverse engineering to work out the circuits of competitors' products. Schematics have always been hard to get, but at least in the old days components had their values marked. Not anymore! – most surface-mount ceramic capacitors have no markings, possibly just a vague tint indicating the dielectric used. Pick-and-place machines have no need to read, they just put on what's in the tube. Using the LCR45 with the optional plug-in SMD03 tweezers illustrated in Fig.1, Fig.17 and Fig.18 produced a solid measuring system. No more messing about with meter probes pinging that unknown cap into the component-eating carpet black hole!

Cost effective

The cheapest alternative to the Peak LCR45 is a Tenma 72-6948 impedance meter (which only works at 1kHz) and a separate LCR meter, both only offer 3.5 digits, as opposed to the Peak's 4 digits. Together, these would cost over twice the price of a Peak. The only advantage of the Tenma is its large display, which is useful for teaching.

An OLED option for the Peak analysers would greatly improve visibility, but then battery life would be very short. I notice the unit uses the unusual mini 12V GP23A battery – just like the older Peak LCR40. I have to keep these batteries especially in stock for my Peak analysers. The GP23A will last a long time, thanks to the Peak's current consumption of 4mA. Also, the LCR45's reading speed is now almost 10-times quicker than the old LCR40.

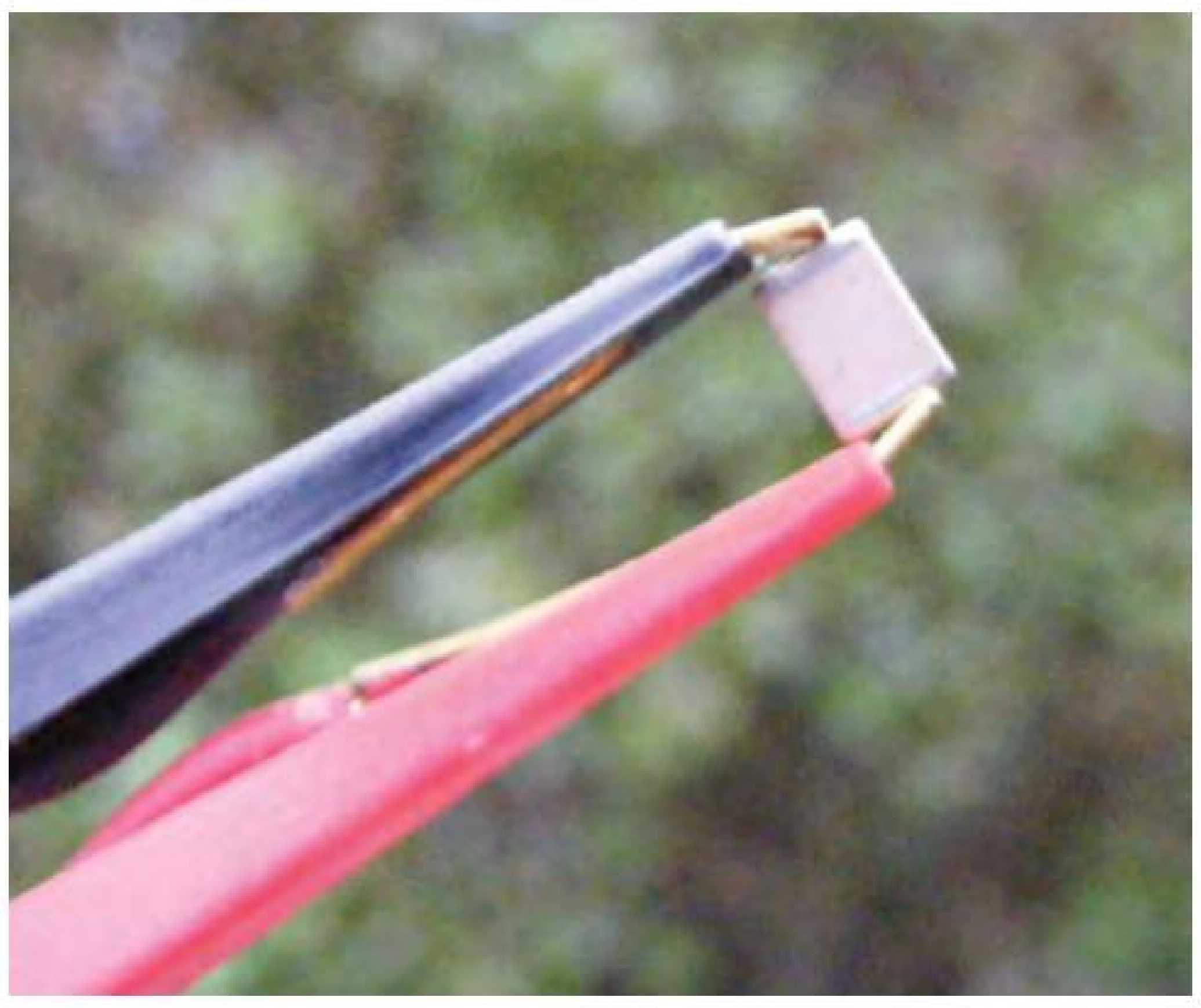

Fig.17. Surface-mount tweezers are available. Here they hold a typical unmarked ceramic capacitor. It is actually a 3.3nF COG type, but you would never know until you measured it

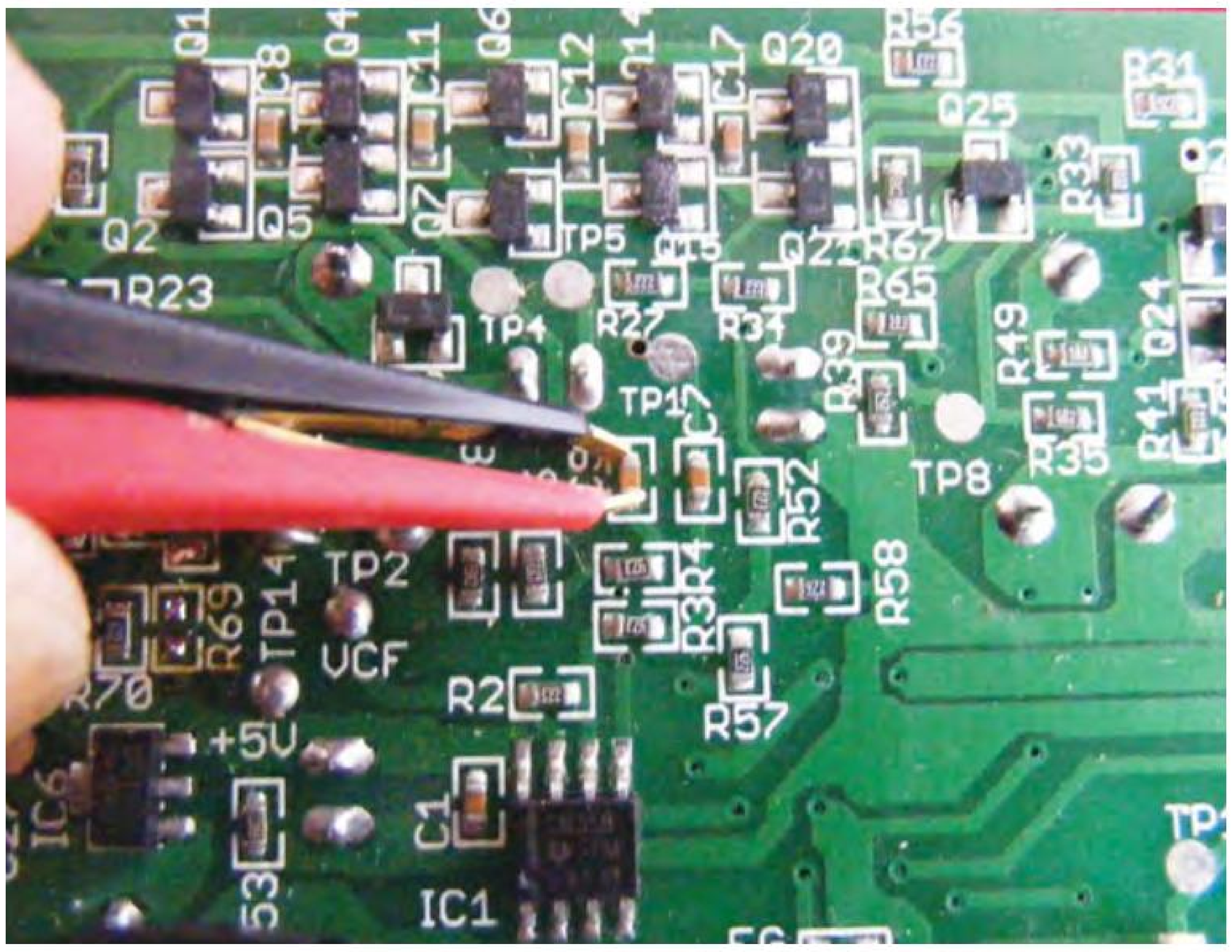

Fig.18. Measuring a capacitor in-circuit on a PCB. Although not an accurate technique, the Peak deals with parallel components better than most LC meters

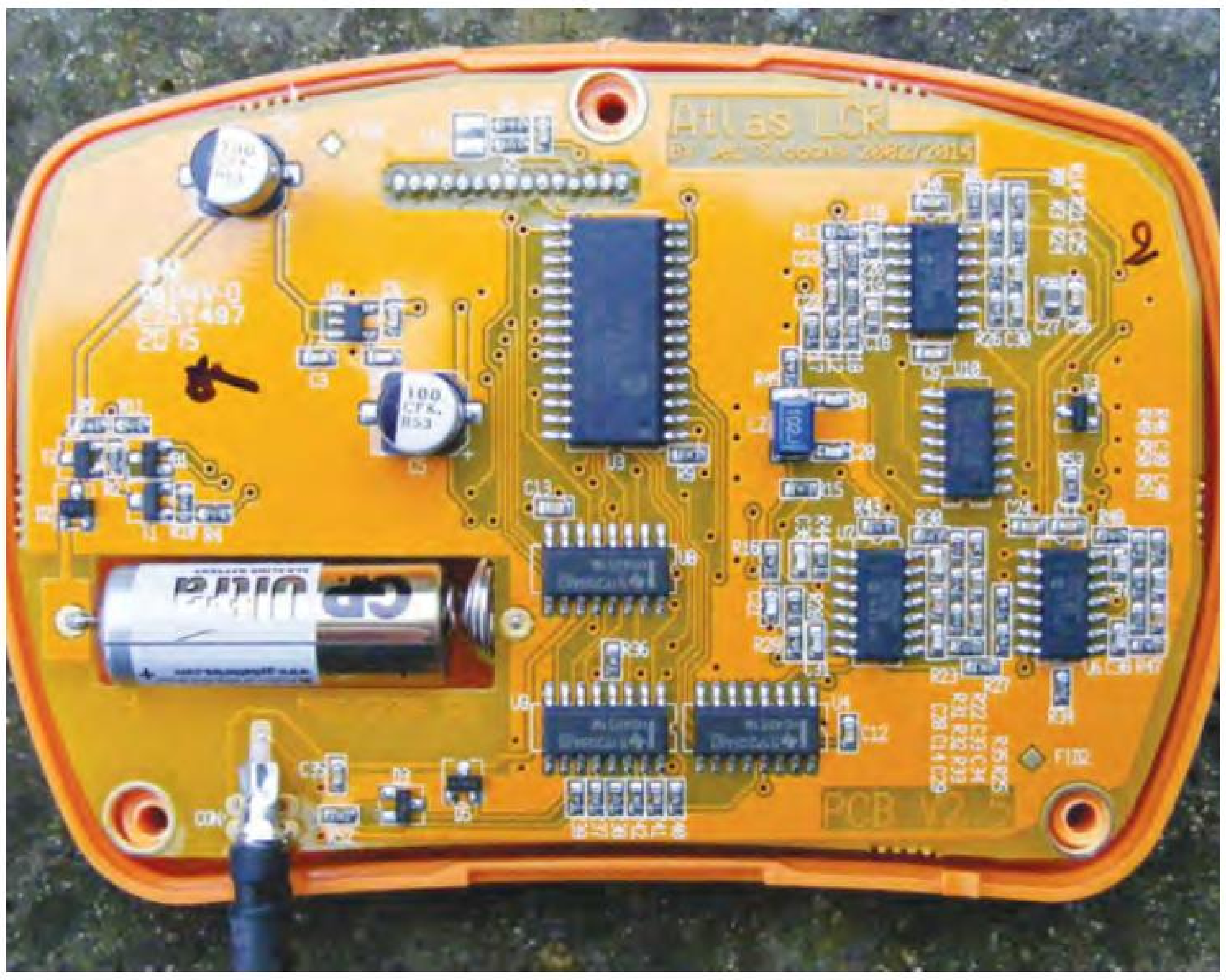

Fig.19. Good-quality internal construction of the unit. (PCBs don't have to have green solder resist!)

Happy termination

Overall I would say this is an essential piece of equipment for any audio or RF circuit designer who can't afford a £5k Agilent rig. Now, if only Peak could do something to measure total harmonic distortion. I'm tired of hiring expensive bench analysers to test power amplifier designs. Imagine it, a little pocket box that would give you THD at say 100Hz, 1kHz and 10 kHz down to 0.001%.

Purchase and further information

The LCR45 is available from Peak for £93 (incl UK p&p and VAT). Further details at: **www.peakelec.co.uk/acatalog/lcr45.html**

DCA75 update

Since reviewing Peak's DCA75 in *EPE*, Sept 2015, I've tested hundreds more devices on it. The new software update installed without problems from the website, even for me – 'Mr. Analogue'! The Peak designer has added a few things I had asked for, such as V_{sat} for bipolar transistors, R_{on} for JFETs and the problem with LM317 voltage regulators was also fixed.

One thing I've noticed is that some transistors that fail to operate in a circuit, still measure fine on the DCA75. I've found this is usually because the device is breaking down at a higher voltage than the analyser tests at. I had some BF245A JFETs used in a ±12V circuit that broke down causing an offset. This problem is rare however, since 95% of transistor failures are definite hard faults.

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NET WORK

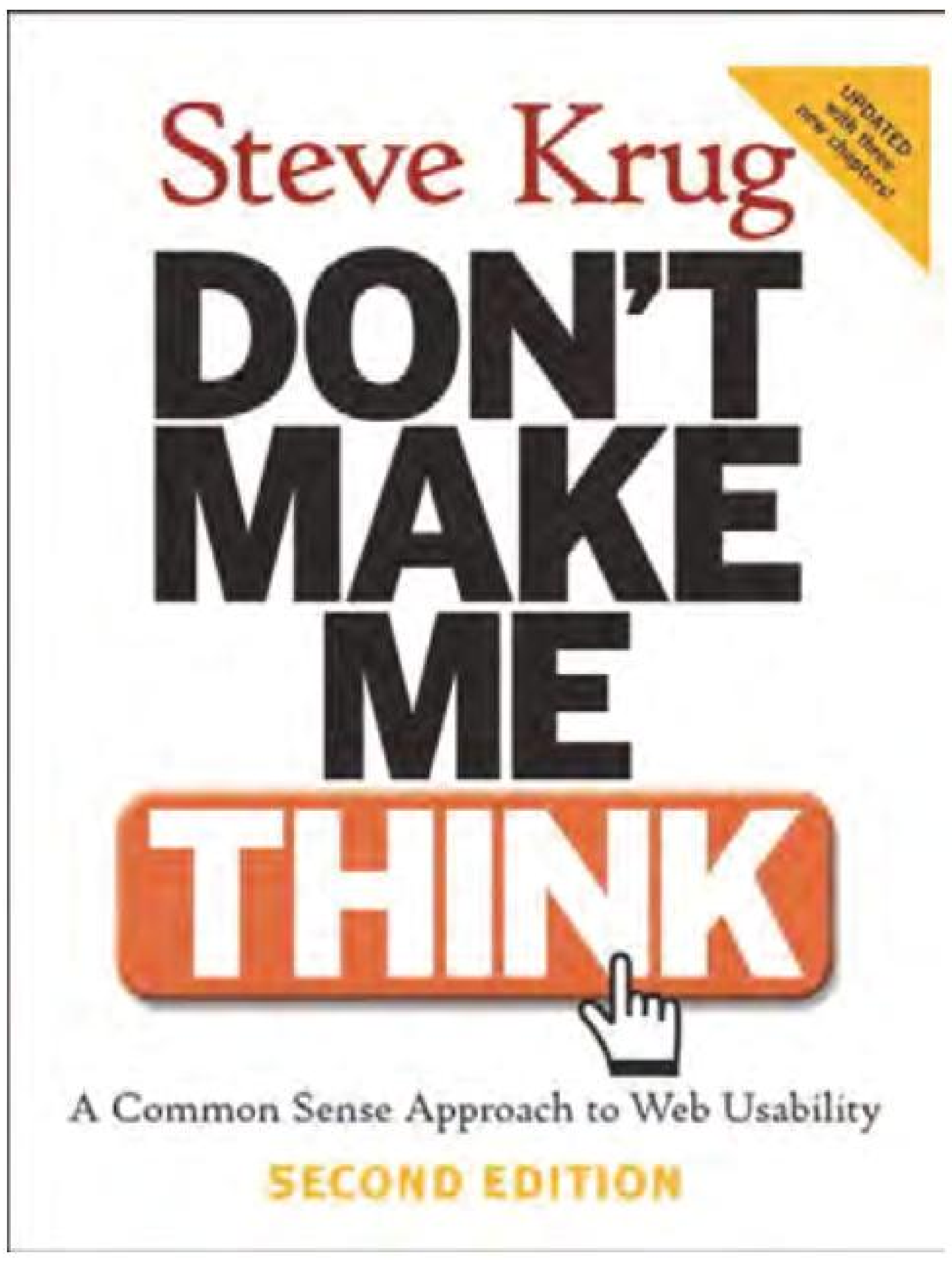
by Alan Winstanley

Form *vs* Function

IN FEBRUARY'S *Net Work* I revisited the market for domain names, showing how the choice for generic top-level domains (gTLDs) has grown from simple dot-coms to include **.plumbing**, **.solar** and many more names that allow domain name users to demonstrate their affiliations. In the UK, domain registrations are ultimately managed by Nominet, the conflicted body that recently announced a 50% price rise in the cost of **.uk** domains from March 2016, complaining that 'costs have risen considerably since [they] last changed the price, and [they] need to compete in a promotion-driven industry.' This reflects the commercialisation and commoditisation of the Internet and a price review may become a yearly exercise.

This month, I examine what's happening with current website design trends, contrasting the latest styles against the founding principles of early web-based services. I was recently seated in a hospital waiting room, marvelling at someone who was tapping out an email on her smartphone, her blurry thumbs travelling at death-defying speed. I spent the time musing about how easy to use the worldwide web used to be compared with today's over-elaborate online offerings. Originally, websites were silos of information designed for viewing on fuzzy CRT computer screens. They typically had a simple navigation menu along the top or down the side. Invariably, clicking a logo at the top left would return users to the home page so users could find their feet again. On fancier websites, javascripted buttons changed colour when you 'moused' over them. Surfers of the 1990s were spellbound by Intel's new website (in the era of Intel's 'BunnyPeople' and the Pentium processor) whose homepage featured circuits with highlights travelling around their conductors: few users had seen an animated **.gif** before then.

More than anything, web pages were designed hopefully with the mantra of *Don't Make Me Think* in mind. This was the title of a milestone textbook written in the year 2000 by Steve Krug, aimed at shaping an emerging generation of so-called 'new media' designers. The book encouraged the design of websites that were straightforward, intuitive and consistent to use, without letting design (heaven forfend) get in the way of usability, which ensured that surfing visitors did not end up stumbling around or losing their way.


Steve Krug

DON'T MAKE ME THINK

UPDATED with three new chapters!

A Common Sense Approach to Web Usability

SECOND EDITION

Don't Make Me Think *laid down early common-sense rules for web page usability back in the year 2000. (Peachpit/Pearson)*

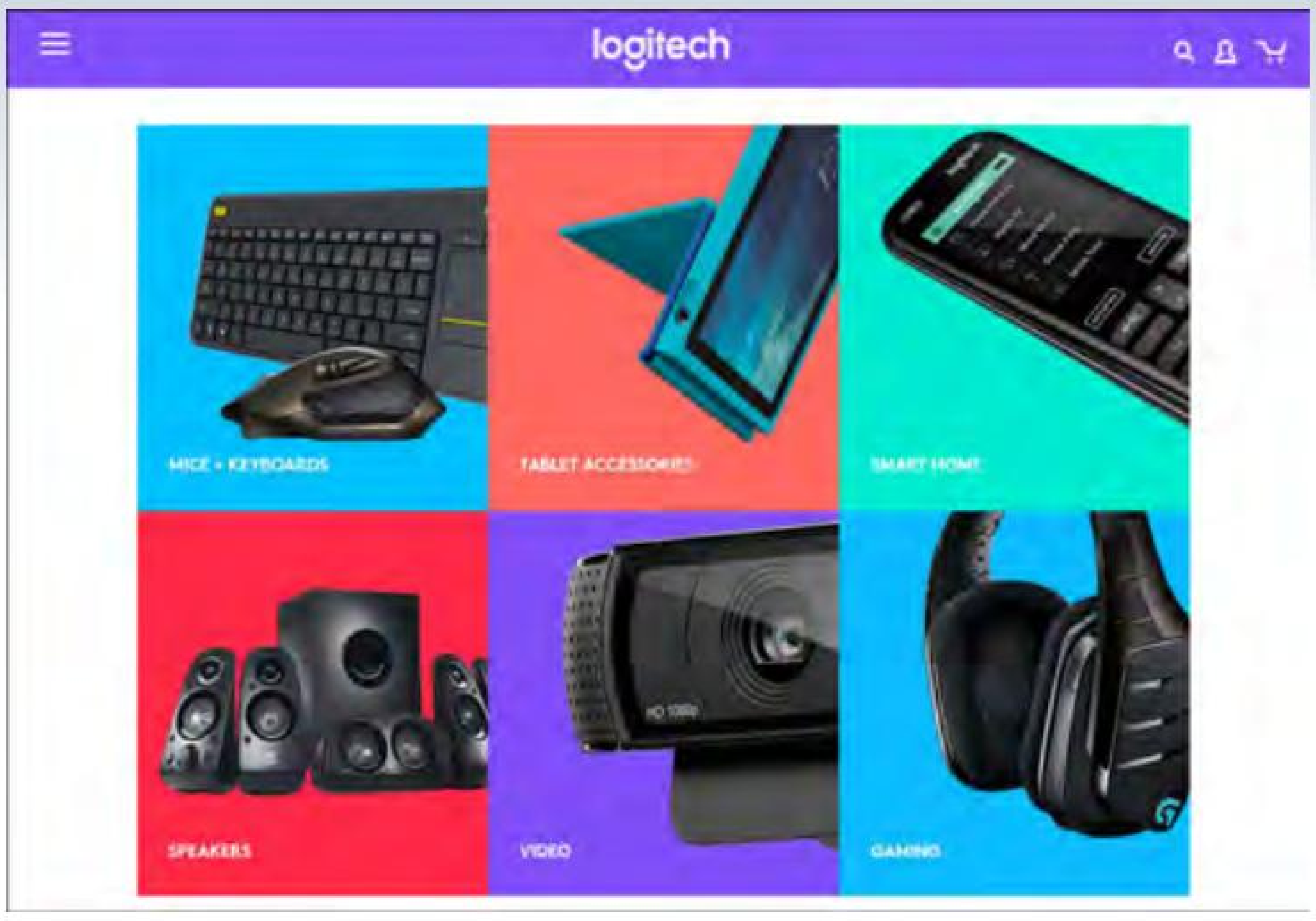
Almost anybody could create a web page by formatting text in hypertext mark-up language or HTML. *EPE Magazine's* earliest website was created using the then-new idea of WYSIWYG web design programs (the fantastic SoftQuad HoTMetaL Pro) to speed the production of static web pages; the primitive results are hosted in the Vault section of the *EPE* website at: **www.epemag.com/projects-legacy.html**

Commercialisation forced the pace, and HoTMetaL was swallowed by Corel and Macromedia's fabulous Dreamweaver, the industry standard of webdesign programs, which was then melded into the Adobe empire of costly subscription-based services. Design techniques continued to evolve, and web designers started to think more in terms of accessibility, tablet users, styling and database-driven dynamic websites instead of 'static' pages that anyone could bash out for themselves in an evening. In came the demand for social networking – a web superimposed on the web – as well as content management systems and blogging using tools such as Wordpress and Joomla, and the face of the worldwide web changed forever.

The tabloid web

In my view, the web's founding principles of *Don't Make Me Think* seem to have been abandoned as we stare at increasingly over-designed, artistically bloated efforts produced by today's crop of earnest 'youngbeards'. No longer is it assumed that website visitors use a PC screen, keyboard and mouse to navigate around menus. Instead, naturally, tablets and smartphones are the popular surfing tools of choice (noting that tablet sales have peaked: everybody has got one) and the idea of swiping, pinching, zooming and flicking around web pages has been cemented into their design ethos. Even though I'm hardly a surfing neophyte, checking around some modern websites on a widescreen monitor leaves me feeling like a non-swimmer thrashing around an Olympic-sized swimming pool, while searching desperately for the ladder. I abandon them all too frequently, feeling very frustrated and short-changed by the experience.

The present design trends originate from mobile 'apps', pint-sized programs offering basic fingertip navigation and simplicity of use for the mass (and largely non-IT literate) market of tablet and smartphone users. Traditional website navigation menus and 'home' buttons are being replaced by cogwheel icons that pop open a flyout menu, or meaningless badges of three dots or bars that supposedly unlock the navigational mysteries of the website as if by magic. It appears that websites are no



Logitech's redesigned website typifies current trends with flat styling and app-like behaviour – the author gave up on it

longer to be considered as sites but as 'apps' in their own right. Then you have to scroll down acres of increasingly overblown, often animated and distracting, photo-quality 'hero' images (a term borrowed from print publishing) to get to the information that you seek, if you're lucky. Sometimes the journey is so long that you forget what you are looking for.

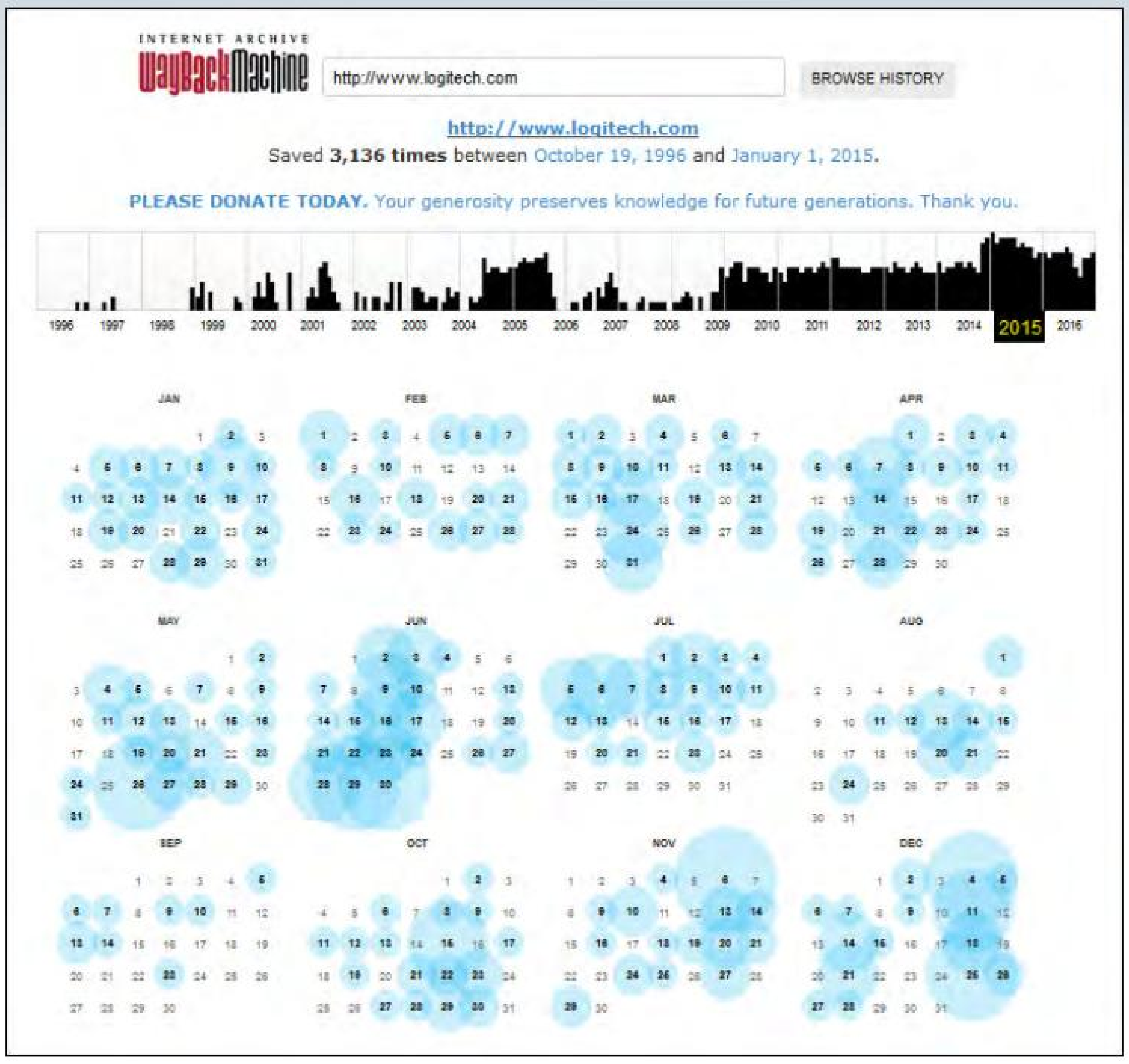
In the latest version of the book *Don't Make Me Think*, one chapter is entitled *Help! My boss wants me to ______. Surviving executive design whims*. This likely reflects the ever-present conflict that exists between 'creatives' and hard-nosed business people. Probably everything that is going wrong in web design trends was typified by my experiences when fetching some webcam software from Logitech's website (**www.logitech.com**). Last Christmas, a Logitech HD webcam was re-installed (as featured in *Net Work*, February 2012) to allow some festive Skyping with friends who were holidaying abroad. Luckily, I had the original installation CD, but the software's built-in web hyperlinks no longer worked because Logitech had deleted the target web pages (Happy Christmas to you too!). Their website had been redesigned to reflect current fashions: getting in the way of pinpointing some information. I found acres of flat, bland coloured tiles, truly overpowering product images and endless scrolling that needed much futile mousing to navigate around.

Nowhere were the necessary legacy files to be found, and only by digging deeply in forums did I learn that a Logitech webcam 'update' had rudely disabled some original features that I wanted to re-install (great!), so I would have to use the earlier version's software. Eventually, I checked the **Wayback Machine** at **archive.org** to find the legacy software on an archived copy of Logitech's website from several years earlier, and finally my webcam was up and running again. Needless to say, Skype then attempted another upgrade, too, and more flat 2D icons were hammered home.

Another prime example (in my view) of this almost tabloid-style of presentation is Nominet's web presence at **www.nominet.uk/products-services**, with screen-hogging animated hero images that could induce motion sickness in its visitors, rather than focussing on the role of giving out essential information in a 'tightly designed' website that is informative and easy to travel around.

End of an era?

Although *Net Work* is not a computer column as such, the gap between IT and networking is blurring fast, and more signs of dumbing down and minimalist styling can be found in current operating systems. Users generally seem to love or hate the flat style of Windows 8 or 10 and many are resigned to what is happening: the way we are forced to use our computers is changing, and not necessarily for the better, either. At *EPE* we like to think we know our readership well and many readers are highly skilled PC users; it's common to use a Windows PC as a tool for projects, including PIC programming, data logging or as a valuable part of a test equipment line-up. For 20 years it has been straightforward enough for us to own and run a PC, or build or reformat one if needed: just launch the Windows disk and tap in the serial number, then install your choice of programs, download a ton of patches or drivers, enter more serial numbers and restore any backed up data as needed. Although a bit of a chore, at least it has been manageable and the electronics hobbyist's life has been satisfying and rewarding in that respect.



Saved **3,136 times** between October 19, 1996 and January 1, 2015.

PLEASE DONATE TODAY. Your generosity preserves knowledge for future generations. Thank you.

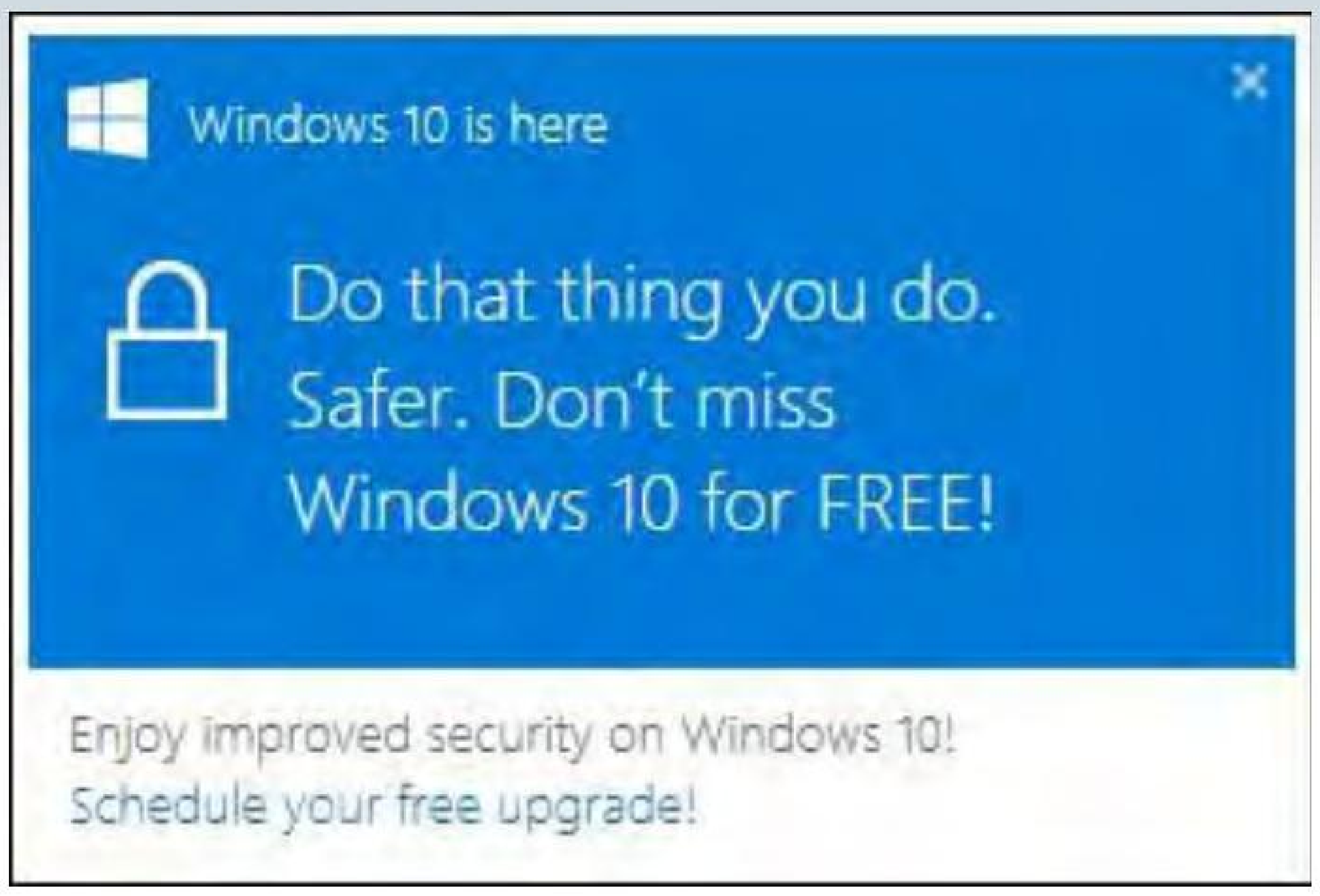
*The Wayback Machine is a goldmine of legacy web files and information. The timeline and calendar show archiving activity (***archive.org***)*

I fear the sun is going down on the way in which we enjoy using a PC as part of our hobby: that's because a concerted effort is under way to turn Microsoft Windows into a constantly-evolving OS with the Internet playing a leading role. Microsoft wants everyone to sign up to Windows 10 and then future updates will consist of a rolling program (pun intended) of incremental patches rather than an entirely new release.

'Updates'

The same approach has long been adopted by Android (currently on Version Marshmallow – KitKat and Lollipop are history), Google's mobile OS that has its roots in Linux. As I write this column, my HTC One has downloaded another 180MB Android update, requiring 292 app updates (it says here) and it managed to lose my Wi-Fi passwords in the process. While the Windows 10 update is currently free, many power users will deplore Microsoft's attempt to wrest control of their desktop PC this way. *EPE* readers know exactly how they like their PC to look and feel, and there is often intimate knowledge of the underlying system, acquired through many years of skilful use that enables one's PC to be tweaked and tuned accordingly.

Readers will sympathise with *Net Work* regular **Steve Alsop**, who writes in again: 'There has been another massive and major update this week to Windows 10, which annoyingly changes a lot of settings without telling you. For example, in: **Advanced system settings/Advanced tab/Environment Variables**, under both User variables for (xxx) and under System variables for both the TEMP and TMP variables, I use **C:\Temp** (I create a Temp folder on the **C:\** drive, or when I have a slave drive I use **D:\Temp** instead). This directs all garbage into one folder because Windows or apps do not always remove their temporary variables when closing or shutting down, so you end up harbouring masses of rubbish. When it is always in one folder at least you can do spot checks and delete the items. This last Windows 10 update altered these settings. I really


Windows 10 is here

Do that thing you do. Safer. Don't miss Windows 10 for FREE!

Enjoy improved security on Windows 10! Schedule your free upgrade!

Windows 7 and 8 users can expect more of this kind of thing. The nag screens can be removed (see text) – for now anyway

do despair with W10 as this second update has taken lots out of working time.'

Problems with Windows updates caused much displeasure in the household last Christmas, as Microsoft disabled the Yuletide Advent Calendar, an annual family treat downloaded each year from **jacquielawson.com**, whose Flash-animated ecards are joys to behold. After updating the Windows 8 machine, the Advent Calendar vanished halfway through the month for no reason. It was eventually downloaded again and re-installed, and happily the PC had remembered the original settings so the countdown to Christmas could carry on where we left off, but the Windows update wasted a lot of time and severely damaged the confidence of some inexperienced PC users. Certain other programs are also being deliberately disabled by Windows updates.

At the time of writing it is not clear whether or not Windows 8 / 10 updates will become compulsory in coming months. How to remove the 'Get Windows 10' popup is now well documented – in Windows 7, delete Windows Update KB3035583 (also see *Net Work*, January 2016), but on the shiny new Windows 8 PC I mentioned in the same issue, I went further: the upgrade reservation can be uninstalled completely by removing KB2976978 (Compatibility Update for Windows 8 / 8.1). Microsoft describes this update as '...diagnostics [that] ensures compatibility for customers who want to install the latest Windows OS.' It's also important to find and right-click them in the list of (pending) updates and choose 'Hide', or they will simply be re-installed again. A registry tweak downloadable from **AskVG.com** at **http://preview.tinyurl.com/pwpu4km** was also needed, which I can confirm worked safely. Having deleted these patches and rebooted, the Windows 10 icon has gone from the Windows 8.1 PC, hopefully for good.

Constant updates and downloads will become a regular feature for PC owners, with programs (like websites) being treated more like 'apps' integrated into an awful GUI, and end-users can expect more compatibility problems to arise as a matter of course. We could even reach the point where the challenge of running a standalone PC finally becomes too unrewarding for our purposes, with much of the power migrated onto the cloud and our PC becoming more like a dumb terminal, Chromebook-style. Expect a lot of disingenuous double-speak as the IT industry strives to change our way of working: it will want to 'help us make a better informed choice' or 'assist us in understanding the latest developments' or 'prepare our systems in readiness for system updates'. I made those up, but you know the kind of thing that's probably coming our way.

That's all for this month's *Net Work*. I can be emailed at **alan@epemag.demon.co.uk** or comments for possible inclusion in *Readout* can be mailed to **editorial@wimborne.co.uk**

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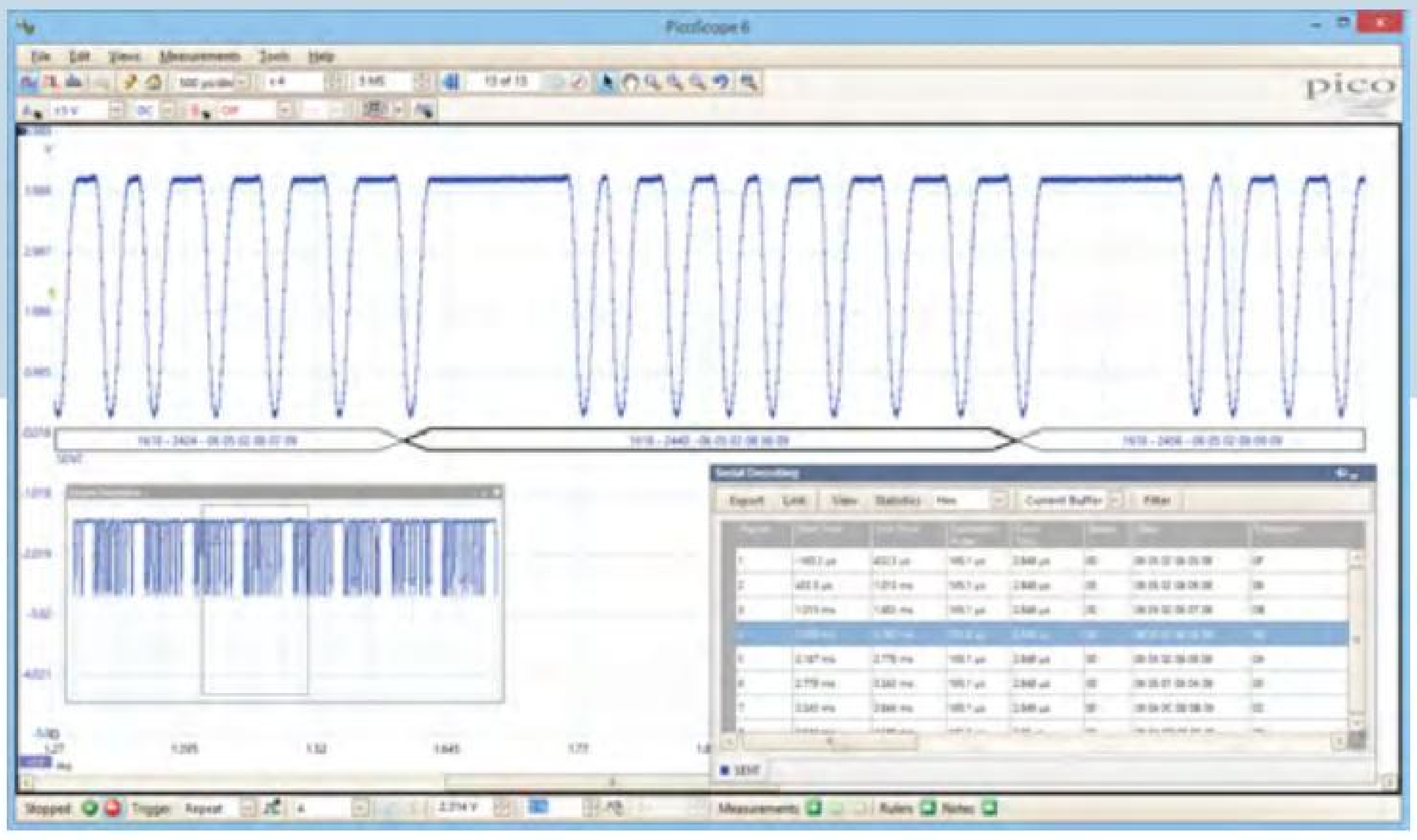

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Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

Getting it to work

NO DOUBT many newcomers to electronic project construction are reluctant to 'take the plunge' with their first project due to apprehensions about the finished unit failing to work. This is not a worry for those with years of experience at project building. They have the necessary test gear to sort out most problems, and the technical knowledge needed to exploit this equipment. A complete beginner lacks both test equipment and technical skills, and, on the face of it, will have little chance of finding and curing problems in a troublesome project.

In reality, the situation is much less dire than this provided the project chosen for the first attempt is something sensible. While it is enticing to choose a complex project to impress your friends and family, to do so is tempting fate. The larger and more complex the design, the greater the chance a novice has of making a mistake during construction. Also, the greater the complexity of the circuit, the harder it will be to locate and rectify any errors. Something very simple and straightforward is a much better choice for a first attempt at electronic project building.

Safety first

There are safety issues to consider when selecting your first project. A device that is battery powered, or is perhaps mains powered via a battery eliminator (eg, the common kind of small power supply contained in a plug), should be reasonably safe. Mistakes could cause damage to components in the device, but they are unlikely to be a danger to human life. A circuit powered from something like a car battery needs to approached with more caution than one powered by a humble PP3, due to the massive currents that can be delivered by a huge battery such as a car type. Although, the low voltages involved mean there is no risk of a severe electric shock, there is a danger of short circuits causing such high current flows that wires melt and insulation burns.

Projects where the constructor builds the power supply that are powered direct from the mains supply, or connect direct to the mains for some other reason are a different matter. The mains supply is potentially lethal, as is any project that connects directly to the mains supply. Even if a project is very simple, if it connects to the mains supply it is potentially dangerous and is certainly not suitable for a beginner. Steer clear of any projects that connect directly to the mains until you have obtained a fair amount of experience at project construction.

Printing errors in project articles are relatively rare these days, and if an error does occur, it is almost certain to be quickly corrected in a subsequent issue of the magazine, or be flagged up on an associated website or chat room even sooner. Totally dud or substandard components were once a slight problem, but modern components are vigorously tested and it is highly unlikely that you will be sold any that are faulty. The handling of static-sensitive semiconductors was covered in January's article, and it will not be discussed again here. Provided you take a few simple precautions there should be no problems with 'zapped' components.

Therefore, provided you buy the right parts and assemble a project properly, it is more or less guaranteed to work first time. Obtaining the right components is admittedly a bit more difficult than was once the case, with a truly massive range of components currently in use. Carefully compare the values and other parameters in the components list with the descriptions in component catalogues. Comparing photographs of the circuit board with the illustrations of components in catalogues can sometimes clarify matters, and prevent the wrong item from being ordered. Once you have the components, there is a vast amount of information available on the Internet that can quickly sort out problems with things like resistor colour codes and cryptic component value markings.

Hole truth

At one time, there were various methods of construction used for electronic projects, but these days the only two methods in common use are custom and proprietary printed circuit boards (PCBs). A *custom* PCB is the more foolproof option. As its name implies, a custom PCB is specifically designed to suit a particular circuit, and it has just one hole per leadout wire or pin. This minimises the risk of making a mistake, and any errors that should occur are likely to be found before too long. If it is not spotted earlier, a mistake will come to light when you try to fit a component in place and find that one or more of its holes in the board are already occupied!

The most popular form of *proprietary* PCB for electronic projects is stripboard, also widely known as 'veroboard'. This is a multi-purpose circuit board that has a regular matrix of holes, and rows of copper strips on one side. With most circuits only a small proportion of the holes are actually used. This makes it relatively easy to make mistakes, and also makes it more difficult to locate any errors. It can take a lot of very careful checking in order to find just one very slight error. A custom printed circuit board is the easier option when building your first project.

In general, the sooner a mistake is spotted, the easier it will be to correct matters. It pays to take a prudent approach and check everything as you build the project. Before soldering a component in place, check that it is the right one and that it is in the correct position on the board. Where appropriate,

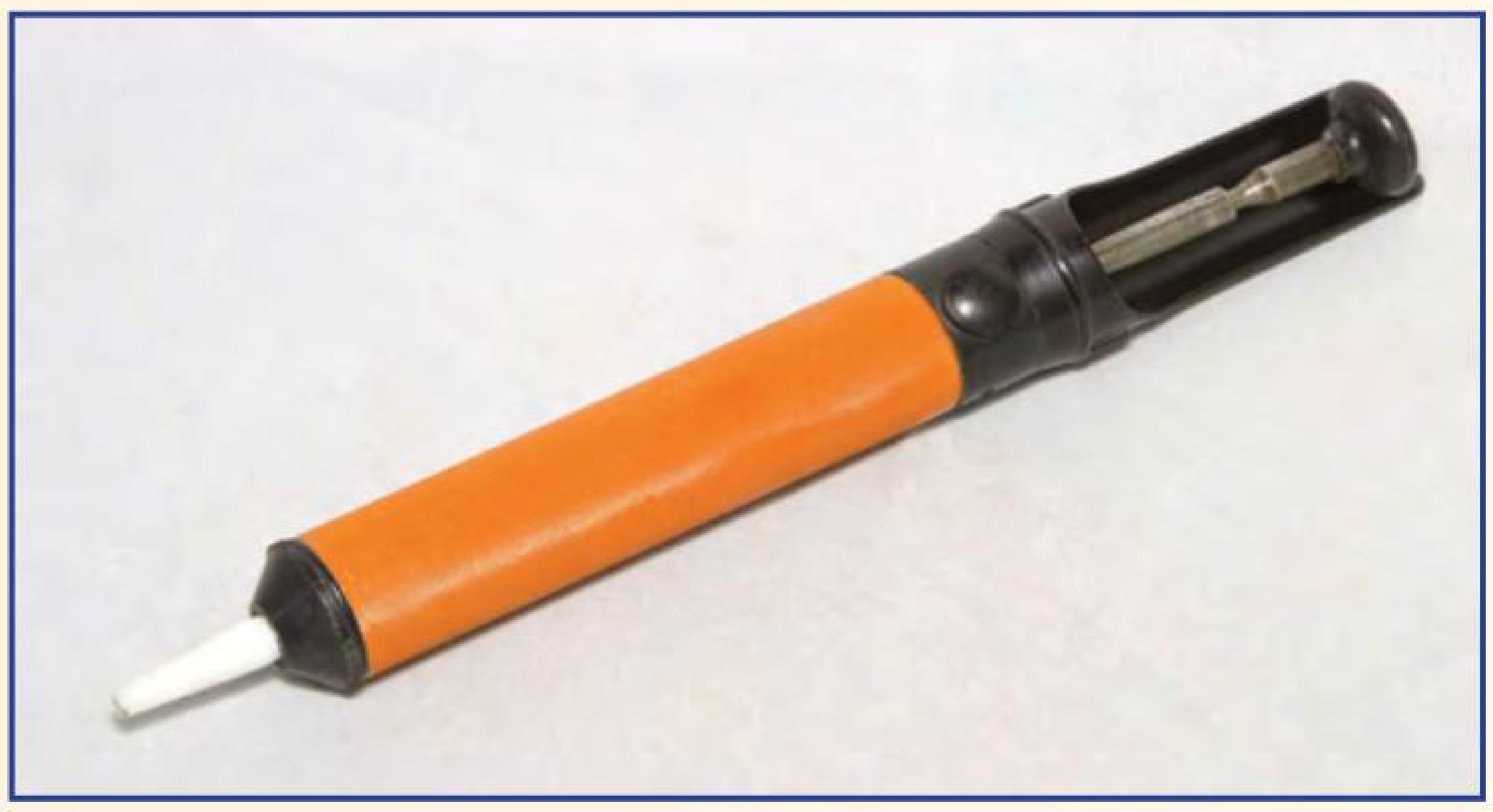


Fig.1. A desoldering tool of some kind is essential when building circuit boards. This one has a spring-loaded piston and it is designed to suck molten solder from the joint

make sure that it is fitted the right way around. Once it is soldered in place, check the joints for any obvious signs of problems, and redo any dubious-looking joints. In order to properly check and correct a finished unit it might be necessary to partially dismantle it. It will almost certainly be necessary to do a certain amount of dismantling in order to get access to both sides of the circuit board. Spotting mistakes early can save a lot of time and effort later, and reduces the risk of any components being damaged.

Big turn off

What do you do if, having assembled a project with due diligence, it still fails to work? When any project is clearly failing to work properly, whether or not it is newly constructed, it is *not* a good idea to leave it switched on. Doing so will not result in any damage in most instances, but it best not to try it and see. Things like semiconductors and electrolytic capacitors connected the wrong way around can cause high currents to flow and subsequent damage. Err on the side of caution, and always switch off non-functioning projects immediately. Then recheck the component layout, the wiring and look for poor soldered connections.

Hot stuff

With the exception of semi-conductors, modern components are not easily damaged by overheating. Even so, each soldered connection must be completed fairly rapidly if damage is to be avoided. Overheated components usually show some obvious signs of damage, such as a darkening or other change in colour. In an extreme case, a component might even become slightly misshapen. Any components that do not look quite right should be replaced. Integrated circuits are mostly mounted on the circuit board via holders, thus avoiding any problems with overheating. Transistors and diodes are often connected directly to the board, and extra care should be taken when soldering them in place.

Caught short

If everything seems to be correctly in position on the board, and the wiring is all present and correct, the most like source of the problem is accidental short-circuits between copper tracks on the underside of the circuit board. The intricacies of modern printed circuit boards, together with the cramming together of many components, make it quite likely that unwanted connections will be produced by small amounts of excess solder. This should be less problematic if the board is coated with a solder resist that is designed to discourage solder bridges, but accidental short circuits could still occur.

Many solder bridges are fairly obvious and will be spotted while the board is being constructed. In most cases they are easily wiped away using the bit of the soldering iron. When there are large amounts of excess solder it is better to use a desoldering tool to remove as much solder as possible, and then redo any joints that have been desoldered. An inexpensive desoldering pump (Fig.1) provides a quick and easy way of removing the excess solder, while minimising the risk of damaging the circuit board or components.

A more awkward version of the problem is caused by minute trails of solder that are often difficult or impossible to see with the naked eye. These are sometimes hidden by a covering of excess flux from the solder. Excess flux tends to get spattered across the underside of circuit boards during construction, and there can be substantial amounts of it on areas of the board where there are a large number of soldered joints. There are various flux removal products available, but some firm brushing with a small brush such as an old toothbrush should to do the job well enough.

Even if you have good eyesight, relying on it to spot tiny solder bridges is probably a mistake. Using a magnifier of some kind greatly reduces the chances of really thin solder trails being missed, and should be considered an essential constituent of a toolkit for electronic project construction. A small magnifying glass will do the job quite well, but an 8× or 10× loupe (Fig.2) is better. Inexpensive loupes such as those sold as photographic accessories or for inspecting jewellery are perfectly adequate for this application. Provided a board has been properly cleaned, a careful visual inspection using a magnifier should expose any solder bridges. It is good practise to clean and visually

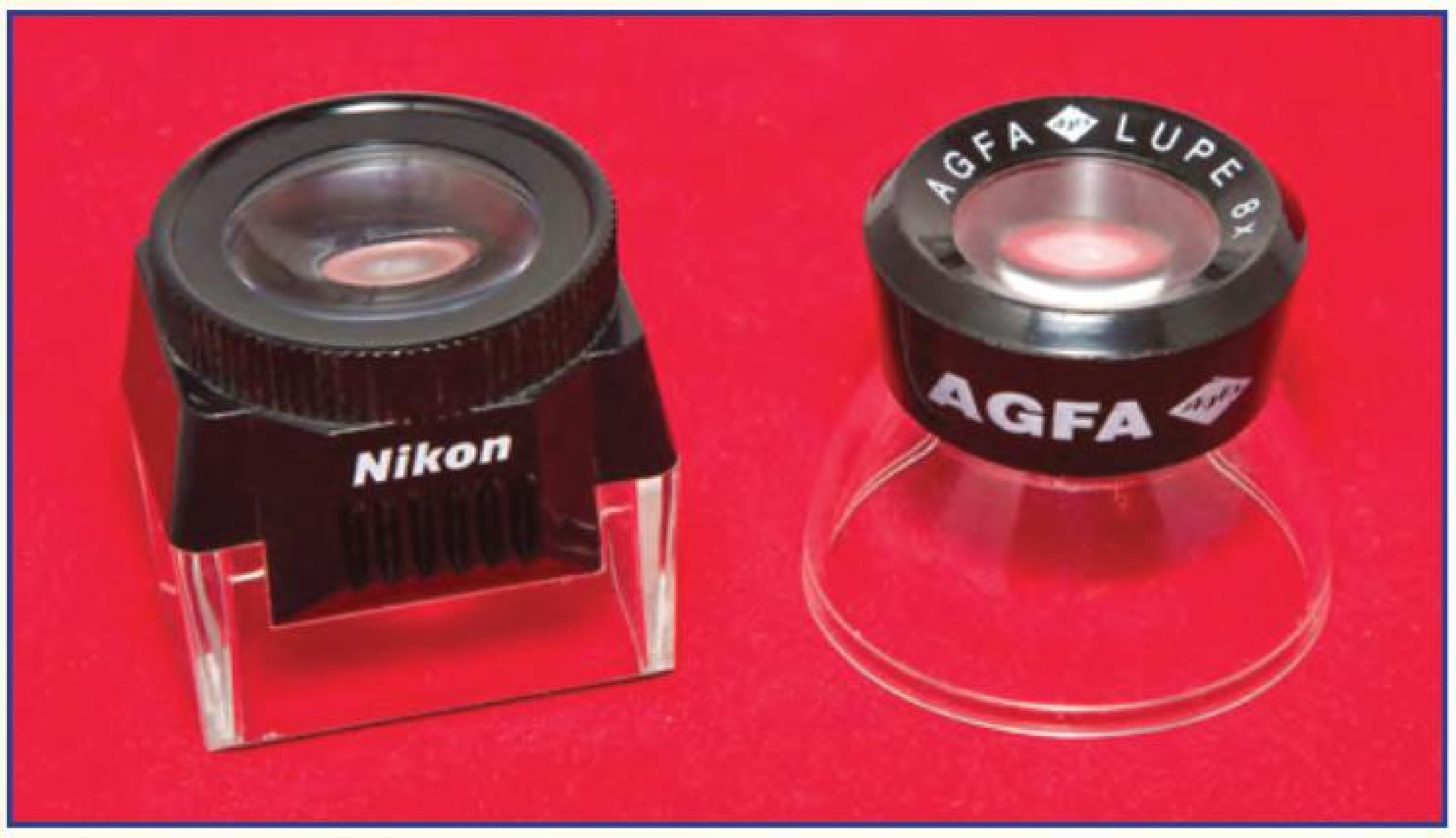
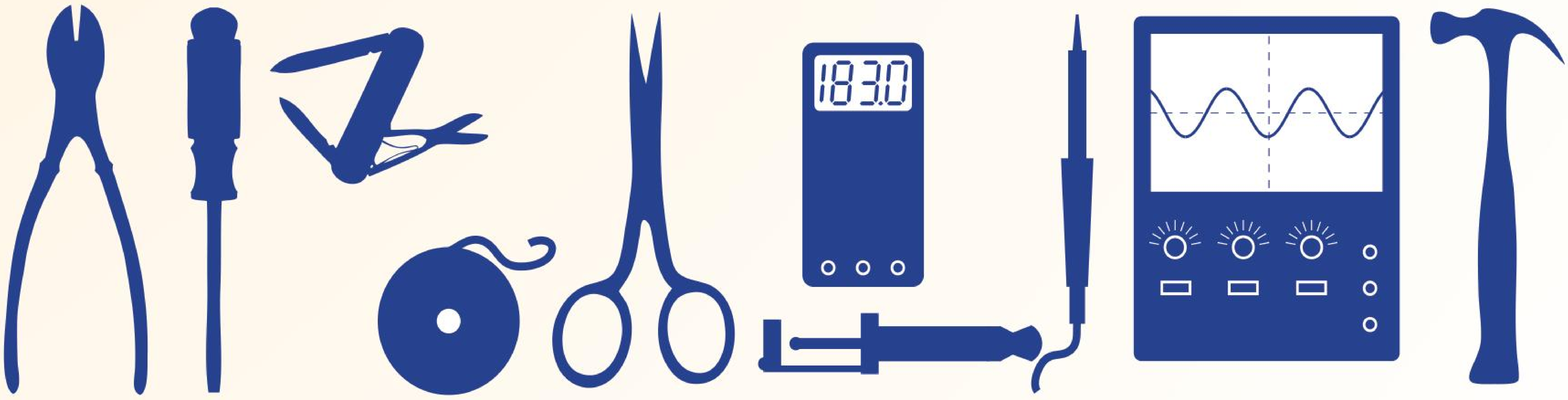


Fig.2. Some sort of magnifier is essential when looking for tiny solder bridges between copper tracks. Loupes, such as these 8× and 10× types are better than something less powerful; for example an ordinary magnifying glass



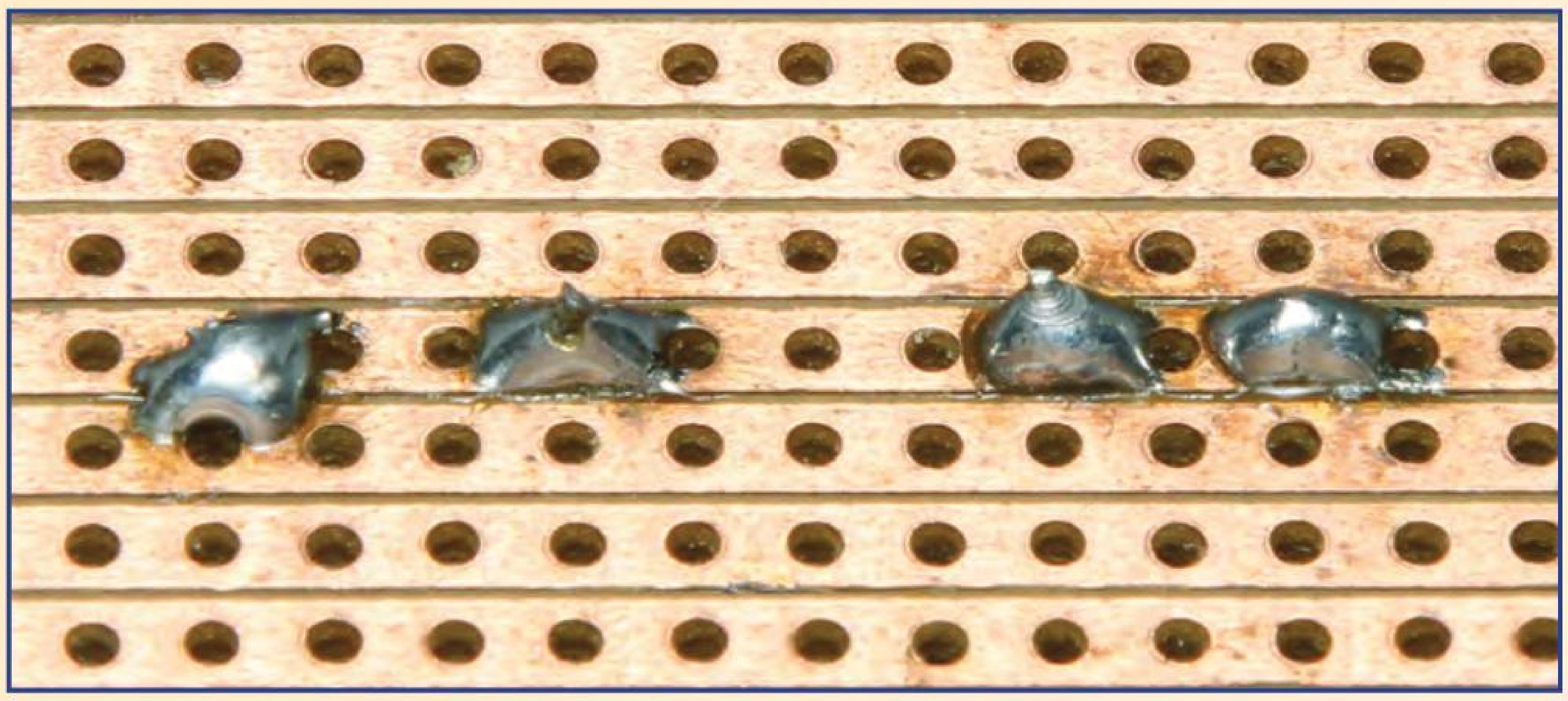


Fig.3. From left to right: 1) corrosion on the lead has resulted in solder flowing everywhere but the right place; 2) perhaps slightly too little solder, but a good joint; 3) dubious joint with too much solder that has not flowed properly, and does not have a really smooth and shiny surface; 4) the leadout wire is not protruding far enough through the board, producing what is likely to be a weak and unreliable joint

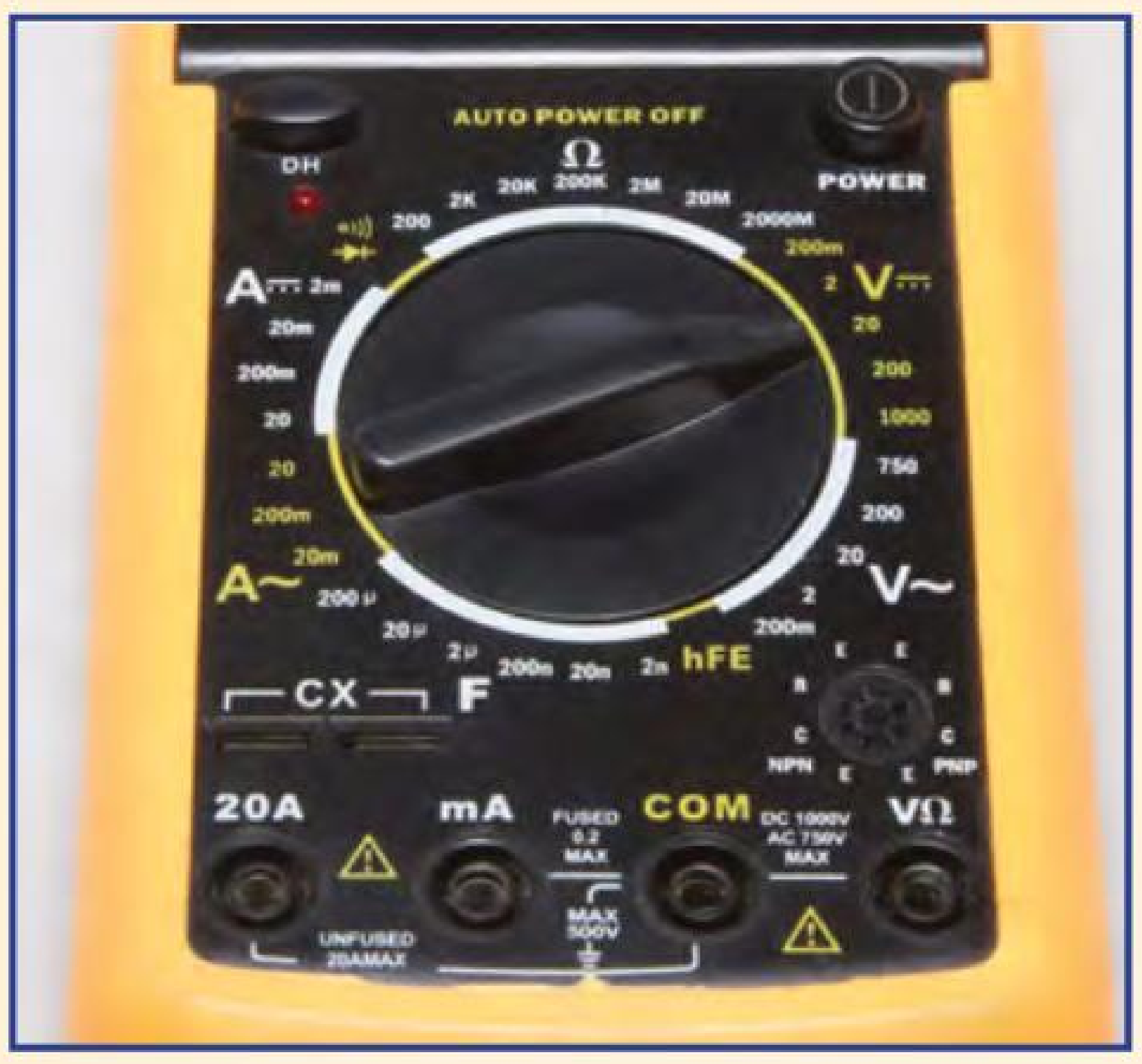


Fig.4. Modern digital multimeters (DMM) can usually measure more than resistance, current, and voltage. This one has facilities for testing transistors and diodes, a continuity tester, and capacitance ranges

inspect every completed circuit board before it is installed in the case.

Modern components and solders greatly reduce the risk of producing bad soldered joints. Even so, if you use you first project to practise and perfect your soldering skills, it is quite likely that there will be problems. Learn to solder using a piece of stripboard, some cheap components such as resistors, and some pieces of wire, before starting your first project. It is a case of 'practice makes perfect', and time spent learning to solder proficiently can save a great deal of wasted time, effort, and money later on. There is not sufficient space available here for a soldering tutorial, but a good one by *Net Work* columnist Alan Winstanley is available at the *EPE* website at: **http://tinyurl.com/jvdocek**. Soldering irons and soldering kits are sometimes supplied with detailed and very helpful instruction leaflets.

Old for new

Probably the most common cause of so-called 'dry' joints is old solder being used for a new joint. This occurs when the soldering iron is left unused for a few minutes before a new batch of connections is started. There will usually be a significant amount of solder left on the bit, but the flux cores will soon burn away, and the solder will start to oxidise. This will not matter if the bit is cleaned before some fresh joints are produced. Soldering iron stands often have built-in sponges. These should be made wet, and they can then be used to wipe old solder from the tip of the bit. However, if you produce joints without cleaning the end of the bit first, the first joint might contain a significant proportion of old and oxidised solder. This might not flow over the joint properly, giving a poor electrical connection. It is also likely to lack strength.

The only certain way of finding so-called 'dry' joints is to check each one using a continuity tester, or the continuity function of a multimeter. Unfortunately, fully testing even a relatively simple circuit board can take quite a long time. Large amounts of excess flux are sometimes indicative of a bad joint, and any areas where this problem was noted should be carefully inspected once the board has been cleaned. 'Dry' joints are often more or less spherical in shape, rather than having the usual mountain-like shape. Also, with dubious joints the solder tends to have a less shiny appearance than normal, and in an extreme case there will be some crazing of the surface.

Be suspicious of any joints that are lopsided with either a lack of solder on one side, or far more than normal. Either way, the solder has not flowed over the two surfaces correctly, and it might not be providing a proper connection. If the joint is flatter than usual, with no sign of the leadout wire or pin, it is likely that the component has not been fully pushed down onto the board, and no connection has been made. Firmly pulling the component away from the board will probably lift the offending pin or lead clear of its hole. A few good, bad and indifferent solder joints are shown in Fig.3.

It a good idea to desolder and redo any joint that is in any way out of the ordinary. Problems with corrosion on component leads are rare with modern components, and the flux in electrical solders is very good at dealing with contaminants. However, it is still a good idea to look at both surfaces for any signs of contamination, and if necessary, clean one or both surfaces before redoing the joint. Any corrosion or other contamination can be removed from the surfaces by gently scraping them with the small blade of a penknife.

Even if you do not have a great deal of technical knowledge, a cheap digital multimeter (DMM) is more than a little useful when things go wrong. It can be used for simple tests such as continuity checking, making sure that the battery voltage is adequate, and that power is actually reaching the circuit board. Any multimeter should enable switches, plugs/sockets, and resistors to be checked. Many also have facilities for testing transistors, diodes, and capacitors (Fig.4). A multimeter is a piece of equipment that should be obtained sooner rather than later.

Fresh pair of eyes

If you cannot find anything amiss, try putting the unit to one side for a couple of days and then take another look at the problem. Sometimes an error that has been consistently overlooked is spotted straight away when you try again a few days later. Ideally, you should get someone else to check the unit against the diagrams. A fresh pair of eyes might spot something that you have overlooked.

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

The PIR motion sensor

IMAGINE the scenario, you're coming home from work, it's late in the evening and very dark; you can barely see your nose in front of your face. You struggle to get your key in the door and suddenly the light turns on. Your motion activated it as you approached the door – isn't technology wonderful?!

Last month, we talked about beginning the New Year with a fresh start and getting on board with version control, repositories and bug tracking. This month we're going to take a look at motion sensors. These sensors allow us to detect whether a human or an animal has passed in front of the sensor and allow us to perform some action based on this function; for example, turn on a light or set off an alarm. They're used all around us, and many of us have at least one in our home as part of the alarm system. They seem simple enough, but as we're about to find out, they can be complicated and there is some very interesting technology behind how they operate.

Passive infrared

Passive infrared sensors (or PIR sensors) are 'passive' because they do not generate or radiate any energy in order to detect changes in the infrared spectrum. These devices use two infrared sensors, positioned side by side and calibrated to each other, which detect the energy given off by surrounding objects. The two sensors then subtract the different infrared levels measured and output a signal based on this. Take the example of someone walking in front of the sensor pair. One side will measure the ambient background level of radiated energy and the other side will measure a *changing* level caused by the person. Once the person has passed, both sides of the sensor will be balanced again.

What is infrared?

Infrared is an invisible radiating energy that operates in the electromagnetic spectrum at frequencies between 300GHz and 430THz (or a wavelength of 1mm to 700nm). It is used in industrial, scientific and medical environments. It has been deployed in night vision devices to give the user vision without illuminating the area; in astronomy to gain insight into dusty regions of the cosmos; thermal imaging of overheating in electrical or electronic systems; and observing blood flow in the skin.

The best thing about infrared is that almost all of the thermal radiation emitted by any object, near room temperate, emits this energy in the infrared spectrum. This means that everything in the room emits its own thermal radiation. These emissions are fairly static, but a moving object that emits its own heat signature passing in front of these other objects would cause a change in the emitted radiation that is captured by the IR sensor. It is this change that our motion sensor captures and allows us to detect movement.

The pyroelectric effect

Taking a deeper look inside the physics of infrared sensors, they contain a set of circuits made from pyroelectric materials. These materials generate a voltage depending on the *change* in temperature that they sense. The *change* in temperature causes excitation of the atoms within the material's crystal structure, which in turn causes polarisation of the material – this induces a voltage across the crystal. If the temperature stays at this new level, then the voltage will gradually disappear (through current leakage and other effects). So, if a person moving in front of the sensor stops moving then the temperature change and induced voltage will decay. However, if the temperature keeps changing, the voltage will continually be applied (for example, constant movement in front of the sensor). When the sensor is exposed to an infrared radiation change, the induced voltage results in a surface charge. As this radiation changes, so does the charge. A FET is used to buffer this potential. To convert the FET current to a voltage, an external resistor is added (roughly 100kΩ) as seen in Figure 2.

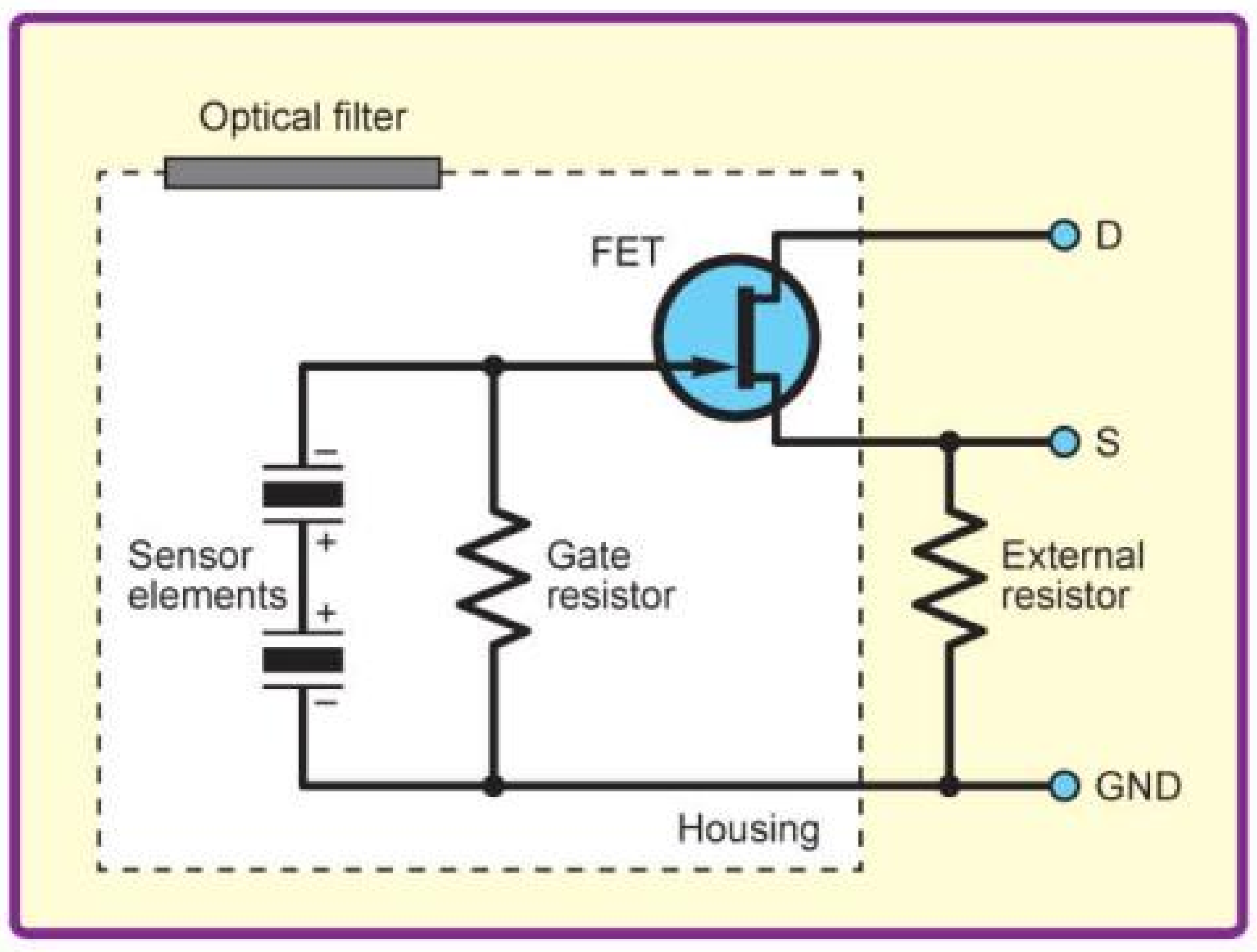


Fig.2. Basic PIR circuit diagram

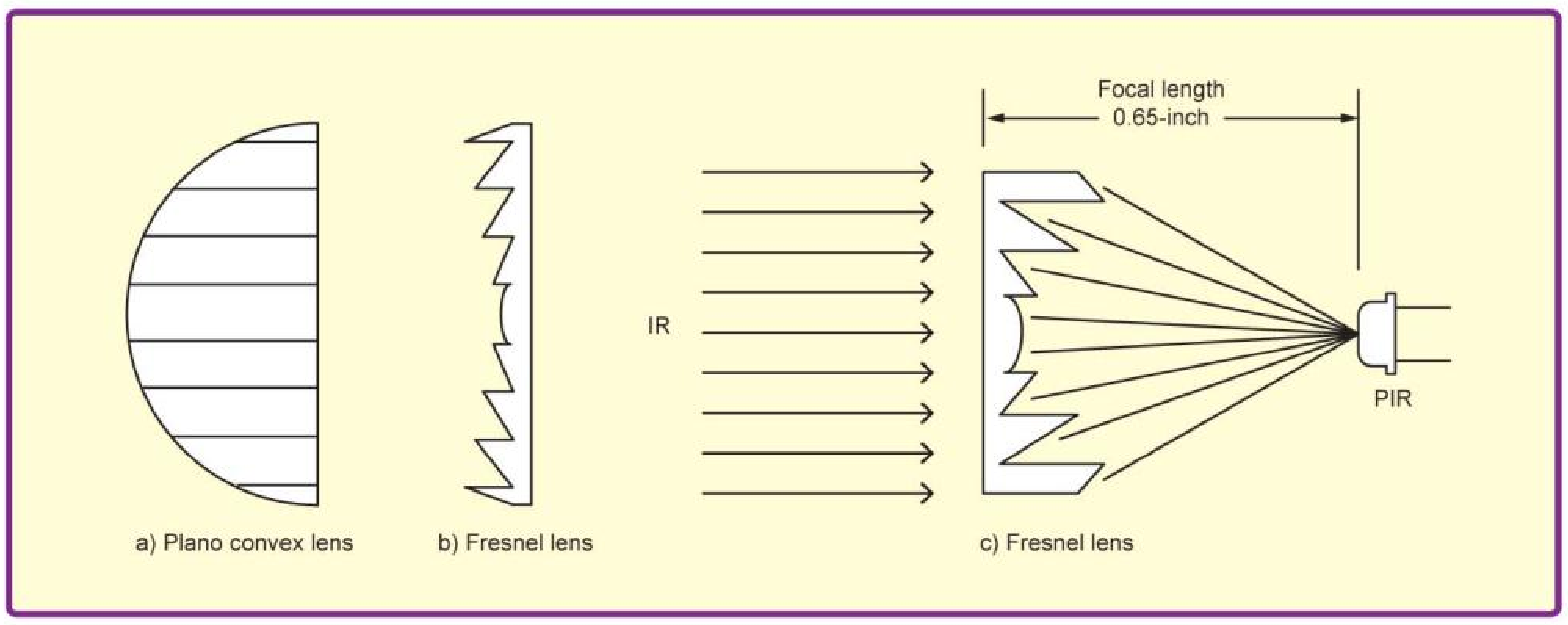


Fig.1. Plano-convex and Fresnel lens

Various materials are used in PIR sensors; for example, gallium nitride (GaN), caesium nitrate ($CsNO_3$), polyvinyl fluorides, derivatives of phenylpyridine, and cobalt phthalocyanine. Lithium tantalate ($LiTaO_3$) is a crystal that exhibits both piezoelectric and pyroelectric properties. Lithium tantalate has proven useful for various applications including terahertz generation and detection, cell phones and even pyroelectric nuclear fusion.

Lenses

The sensors themselves have very limited range, typically only a few centimetres. However, the addition of a lens, can increase this up to 30 meters. The specific lens type used for PIR motion sensors are known as 'Fresnel lenses' (see Fig.1b). These lenses are 'plano-convex' (one side of the lens is flat, the other side is convex, see Fig.1a) that have been collapsed in on themselves, while still maintaining their optical characteristics. The FL65 Fresnel lens is one such lens that is ideal for use in PIR motion sensors. It is 1.5-in square, has a focal length of 0.65-in and has a 10-degree field of view. This specific lens comprises an infrared transmitting material with an IR transmission range of 8 to 14µm (micrometre), making it the most sensitive to human body radiation, which is roughly 10µm in wavelength. Fig.1c shows the infrared radiation as it hits the Fresnel lens and how it is focused onto the PIR sensor with respect to its focal length.

You may well have seen Fresnel lenses as a plastic, ribbed sheets used for cheap, but flexible magnifying lenses. They are also commonly used in lighthouses and can be as big as 3700mm in diameter, such as in the Makapuu Point Light in Hawaii, which uses over a thousand prisms to form its lenses (see: **http://tinyurl.com/nssg5hg**). Their big advantage is they can focus light without using huge volumes and masses of glass.

Which PIR motion sensors to use?

There's quite a number of PIR motion sensors on the market available from Adafruit, Sparkfun, Farnell and eBay. Each of these have their own unique advantages and disadvantages. This is where it can become a bit of a minefield, as I found out when researching this article. Learning more about the technology and understanding exactly what we want is of course beneficial. We need something that allows us to detect motion up to a couple of metres away, and also we want some sort of signal that a microcontroller like our PIC18F can easily discern as an 'event'. Once we detect this event, we can make a decision on what the next course of action is – for example, sound an alarm, turn on a light or open/lock a door.

Analogue versus digital Sensors

Starting off with the most basic motion sensor, we have the analogue dual-element sensor. Some examples are the LHi 968 from Excelitas Tech, the IRA-E710ST0 from Murata and the RE200B. These are the fundamental parts of the PIR sensor itself. They each have two elements, which monitor the incoming IR radiation. If a difference is detected between the two sensors, then the FET is turned on and an output signal is seen. The sensors are constructed from pyroelectric sensor elements connected to the gate of a FET. When a difference in IR radiation is seen across the two sensor elements, a voltage is produced and the FET is turned on, producing our signal on the output (see Fig.2).

Just to be clear, by 'analogue' sensors, I mean the bare-bones pyroelectric sensor with no extra circuitry. The main difference between analogue and their close relation the 'digital' sensor is the type of output signal. Analogue sensors output a nominal voltage during normal operation and will change this voltage by a certain amount based on the detected IR difference in the sensor. This difference in voltage is usually quite low, in the range of 10-15mV peak to peak. The top oscilloscope capture in Fig.3 shows the signal we're dealing with here. It is possible to connect these straight up to a PIC and use an ADC pin to measure the nominal, at-rest voltage value. Then, anything outside this normal range can be a triggered event. Unfortunately, the output can be quite noisy and discerning between noise and a valid response can be difficult and inaccurate. Our ADCs are usually only 10 bits, giving us a resolution of 3.2mV (3.3V divided by 1024 bits), using a supply voltage of 3.3V. This gives us about 5 bits of difference, which really isn't much to work with. This can be used as a simple circuit, but it is very sensitive and can trigger on even the slightest temperature change in a room. While this is a valid solution, I would like to improve on this, which means we will need to add more circuitry to clean up and amplify this signal.

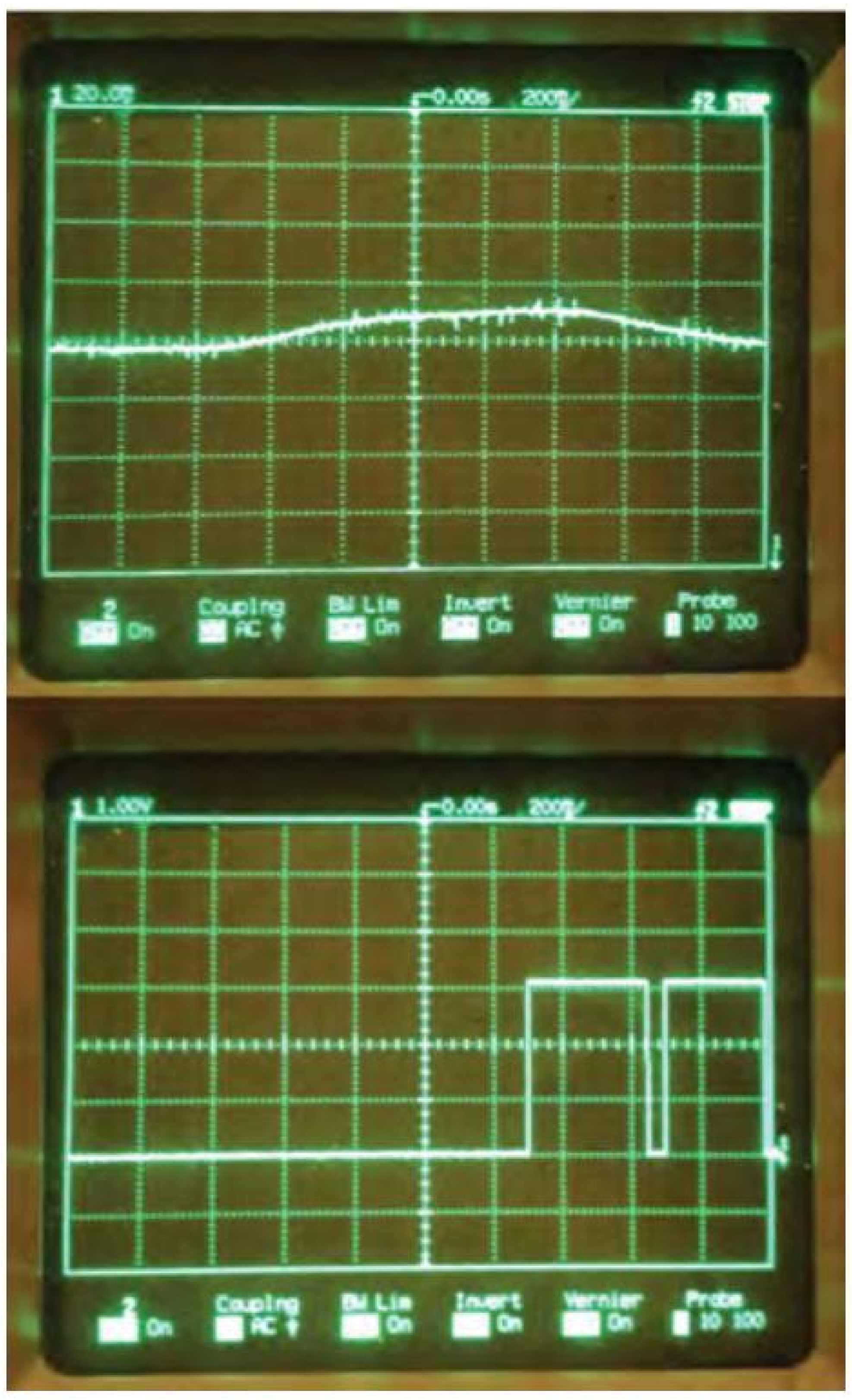


Fig.3. Analogue versus digital output

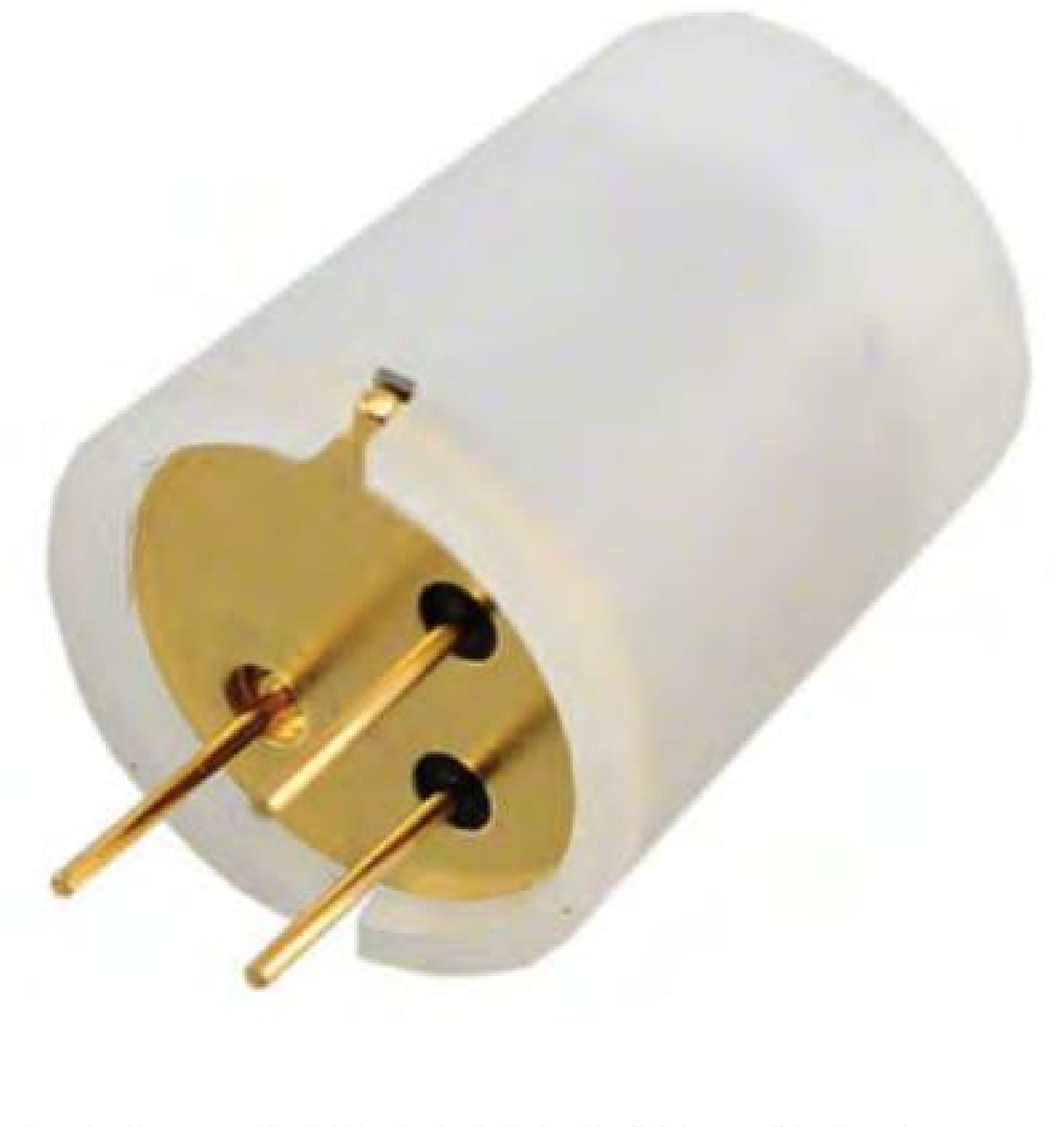


Fig.4. The EKMC1601113 digital output PIR sensor from Panasonic Electric Works

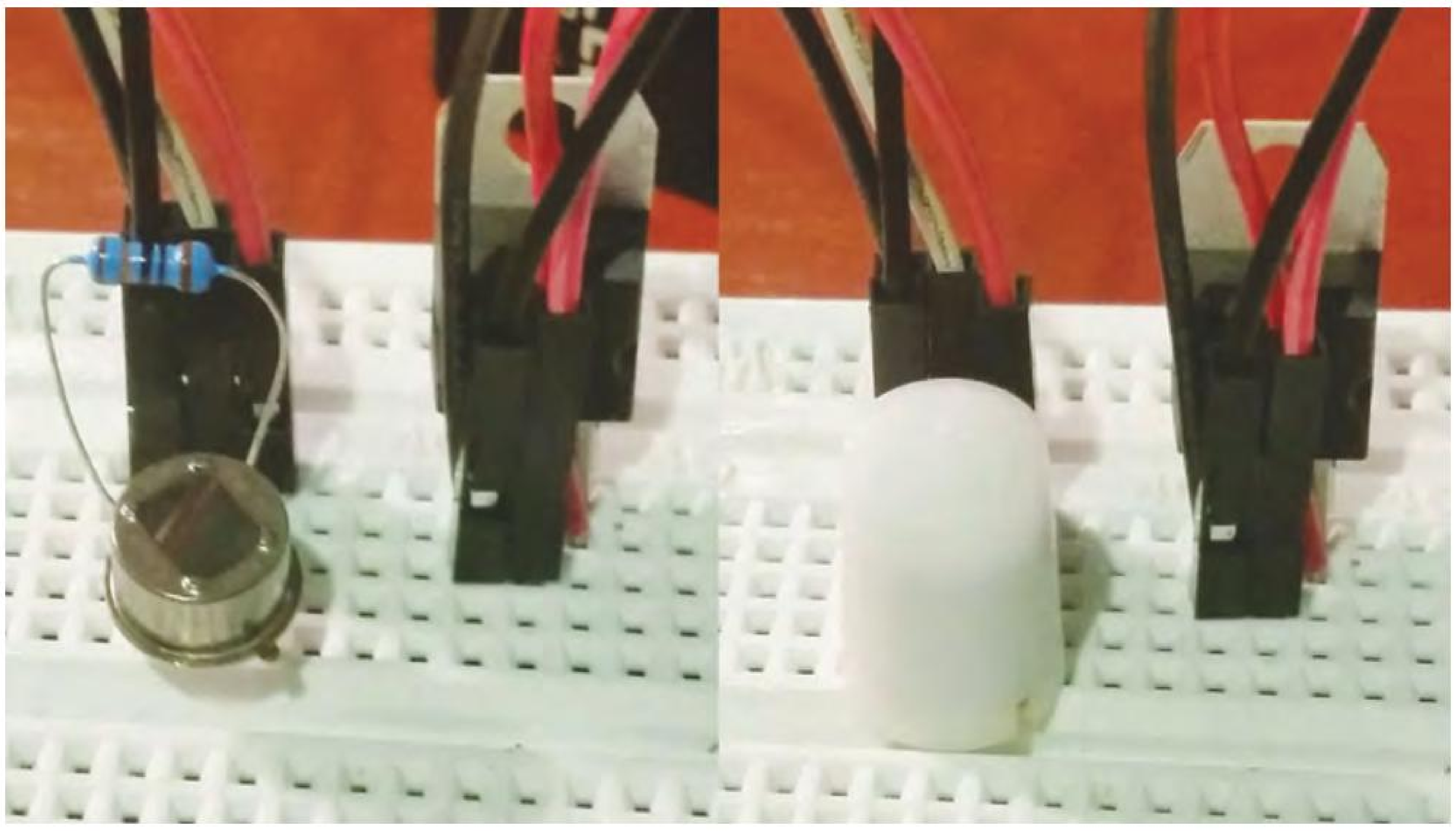
With a digital sensor, we are given a clean digital output that is high when motion has been detected and low when it is at rest. This is exactly what we want. The EKMC1601113 from Panasonic Electric Works is one such digital signal output motion sensor (see Fig.4). It is a fully integrated PIR motion sensor, which contains our Fresnel lens, giving us up to 5m of detection range, as well as containing all of our embedded amplifiers and comparators to give us a beautiful digital output, seen in the bottom oscilloscope capture in Fig.3 (this sensor is also lead free as it is constructed with lithium tantalate, mentioned above). Most of the digital sensors come in at around £7, while the analogue sensors can cost as low as £1.69.

In Fig.5, we have a basic comparison of the Analogue LHi968 and the Digital EKMC1601113. There is only an external 100kΩ resistor on the LHI968 circuit and the output from this can be seen in the top oscilloscope trace in Fig.3. The output from the EKMC1601113 contains no external circuitry and can be seen in the bottom oscilloscope trace in Fig.3. The package sizes are very close in size, but the difference in functionality is huge, from a range of a few centimetres to 5m in the integrated sensor and an easy-to-see output, the digital sensor is clearly a winner.

Wrapping it all up

We've had a look at just a small number of the motion sensors available to us and how they operate. As we compare analogue versus digital output sensors, we might wonder why choose one over the other. The digital output sensor seems like the obvious choice. It is more expensive because it contains all the necessary system components (Fresnel lens, amplification, buffer and comparator circuits), but it's drawback lies in the fact we cannot customise it. Each one is specifically designed for one purpose. However, Sparkfun offer a bulkier version, which allows the user to tune the sensitivity of the sensor and the delay time between triggered events.

There is something to be said for building your own circuit and tuning it yourself using one of the analogue motion sensors described above, plus it is a lot more fun! For a quick design guide to get you started, check out the GLOLABS website (**www.glolab.com/index.html**). You can find a few interesting projects to help you build your own pyroelectric circuits and go beyond to building direction sensing motion detectors as well.



Next month

Now we've covered some basic motion detection, how about some very small motion detection using an accelerometer and some haptic feedback. Next month, we're going to take a look at how three-axis motion detection in an accelerometer works, what we can do with it and how we can recognise a gesture in a handheld circuit and in turn drive a haptic response. And of course we will start to look at connecting these devices to a PIC.

Fig.5. Analogue and digital motion sensor circuits.

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at *@MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

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Seaward Nova	PAT Tester	£95
Solartron 7150	6 1/2 Digit DMM True RMS IEEE	£65
Solartron 7150 Plus	as 7150 plus Temp Measurement	£75
Solatron 7075	DMM 7 1/2 Digit	£60
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CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Voltage references

CIRCUIT SURGERY is usually based on items posted in the *EPE Chat Zone*, but from time to time we also cover topics suggested by the editor, which is what we are doing this month, with the subject of voltage references. These are circuits which produce a constant output voltage irrespective of just about everything – time, temperature, and supply voltage being the key variables of interest. Of these, temperature is of particular importance because the fundamental behaviour of semiconductors is very sensitive to temperature, so it is relatively difficult to achieve constant voltage with varying temperature. This month, we will look at some of the basic concepts relating to voltage references, particularly in the context of making high quality measurements. We will also look at key datasheet parameters. Next month, we will look at voltage reference circuits in more detail.

On first thoughts, a voltage reference may not seem very exciting (it just sits there outputting a fixed voltage), but they are of critical importance in many systems, particular instrumentation and measurement, signal generation and power supplies. Voltage references also provide interesting circuit design challenges in their own right, particularly if high performance is demanded. This is usually the domain of integrated circuits designers, because building precision homebrew reference circuits from scratch is generally not worthwhile due to the availability of good low-cost reference ICs. However, a good understanding of the principles of voltages references will help circuit designers choose the right references, some of the design issues may occur in other contexts and it is simply an interesting case study if you like circuit design. Beyond the innards of ICs, using the highest performance voltage references in a circuit is demanding in its own right – the performance of the best references can easily be undermined by poor design of surrounding circuitry and boards.

Measurement

To further emphasise the importance of voltage references, consider that a digital voltmeter can only measure voltage if it 'knows' what a volt is. This is achieved using a voltage reference to determine (typically) the full-scale (maximum) input voltage of the analogue-to-digital converter (ADC) in the meter. Thus, the better the voltage reference, the better the quality of measurement that can be obtained (of course other parts of the design have to be of sufficient quality too). Voltage references are also key elements of regulated power supplies. Both linear and switching regulators use voltage references as part of a feedback control system which tries to keep the output equal to the reference (or a scaled version of it).

If a measurement is made in comparison to a reference voltage then the measurement quality is totally dependent on the reference quality (here we mean the total reference subsystem, not necessarily just a reference IC). On the other hand, some measurement systems do not depend so strongly on a voltage reference – for example, resistive bridge-based sensors can make use of ratiometric techniques, where the excitation voltage and ADC reference are the same (or directly related) which greatly reduces the dependence of the measured value on the reference.

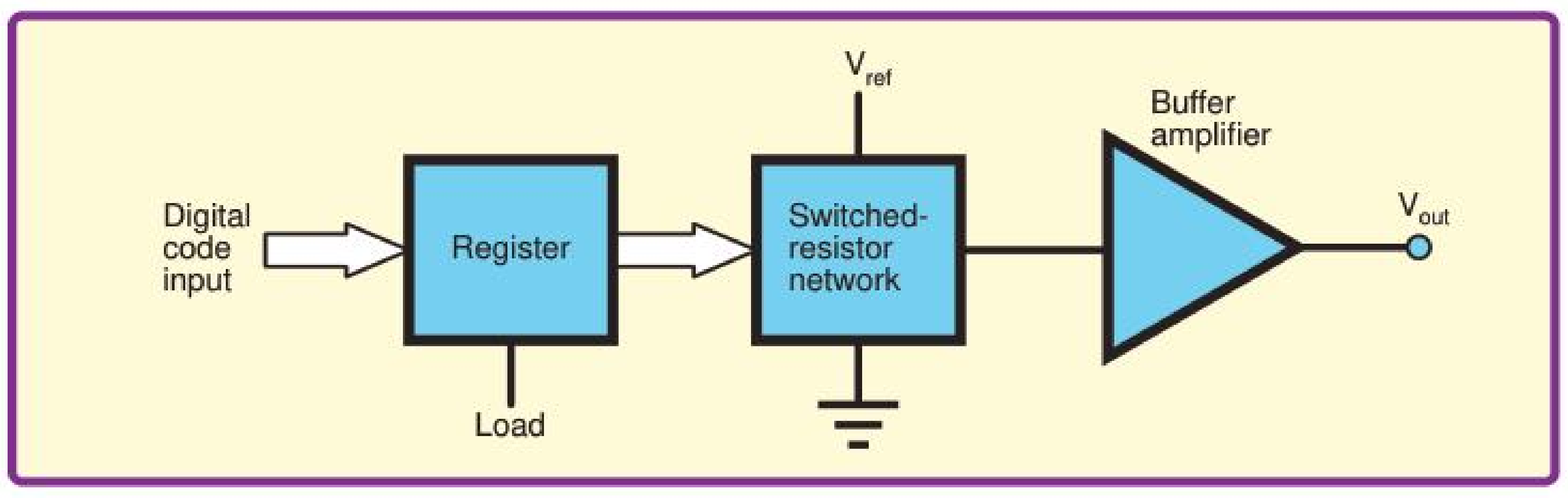

Fig.1. Basic structure of DAC based on switched resistor network

Examples

Fig.1 to 3 show a few examples of circuits requiring a voltage reference. Fig.1 shows the structure of a digital-to-analogue converter (DAC) based on a switched-resistor network. The digital value held in the register controls switches (in the network) which determine the proportion of the reference voltage that appears at the output, buffered by the amplifier. The reference voltage sets the full-scale output voltage, so the accuracy and precision of the DAC is dependent on the quality of the reference.

Fig.2 shows a simplified structure of a voltage regulator. The output voltage is compared to the reference voltage using an error amplifier, which drives a control circuit setting the output, forming a feedback loop. The output control may be linear or switched mode. Just like the DAC, the accuracy and precision of the regulator's output voltage depends on the quality of the reference.

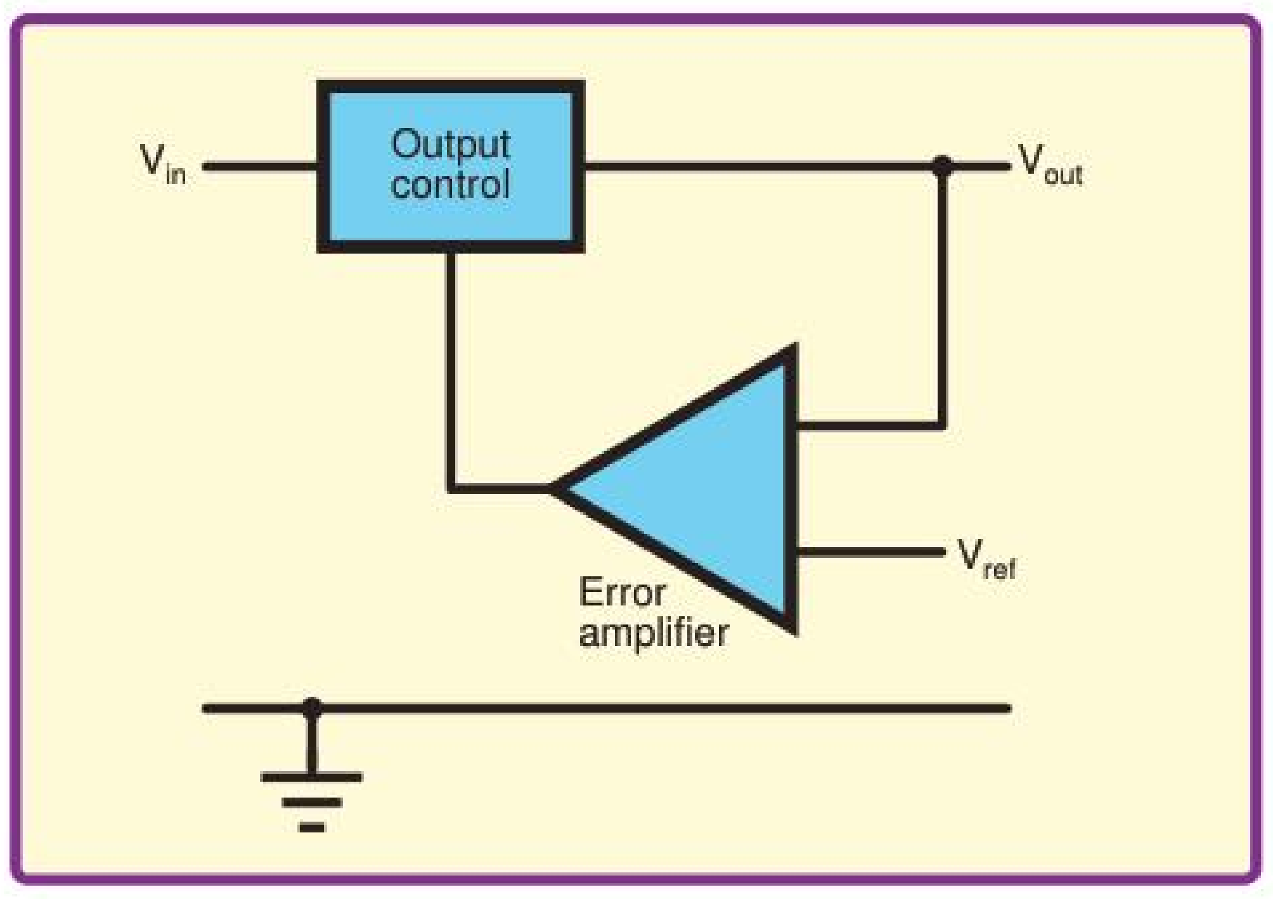

Fig.2. Structure of a typical voltage regulator

Fig.3 shows typical connections between a voltage reference and an ADC. Two versions are shown to illustrate the two basic types of voltage reference – two-terminal, or shunt references, and three-terminal or series references. ADCs have a variety of internal structures. Some compare the input to the voltage reference fairly directly (flash and charge redistribution converters), others contain a DAC whose output is compared with the input voltage – the reference then acts via the DAC. Again, in all cases the ADC accuracy and precision depend on the quality of the reference.

Converter references

When using DAC and ADC ICs you may not have to provide a reference voltage because the device has one built in. Furthermore, many converter ICs allow a choice of external or internal references, often under software control. The AD5663R 16-bit DAC from Analog Devices (**www.analog.com**) is a typical example. The AD5623R has a good on-chip reference, which is off at power-up and which can be switched on by writing to a control register (via the chip's SPI-compatible serial command interface).

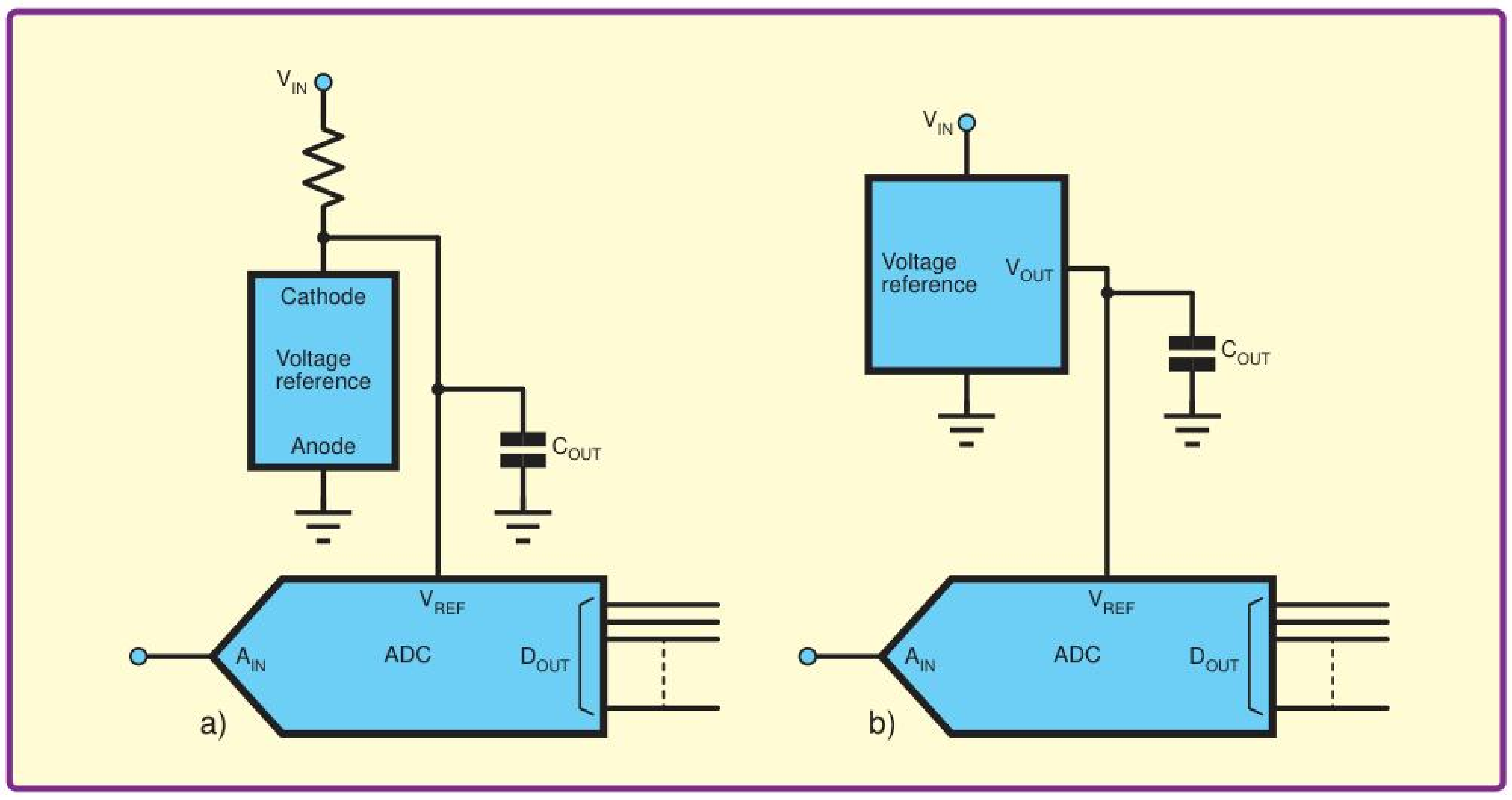

Fig.3. (a) ADC using two-terminal reference. (b) ADC using three-terminal reference

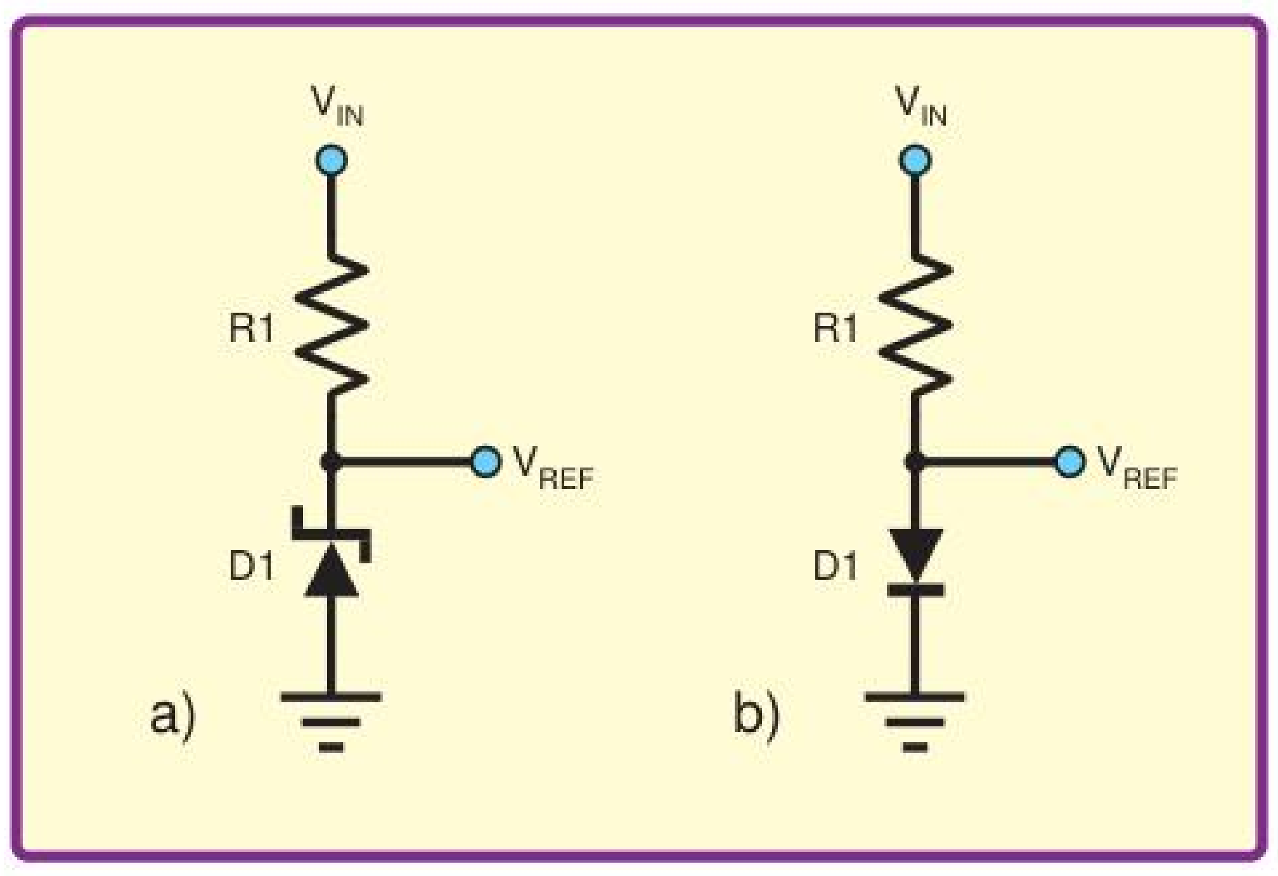

Fig.5. Simple voltage references using (a) a Zener diode reverse biased into breakdown, (b) a forward-biased diode

When switched on, the AD5623R's internal reference voltage is available via the device's V_{REFIN}/V_{REFOUT} pin and can be buffered and used in the external circuit. The device is available in variants with different internal reference voltages. The AD5663R-3 has a 1.25V reference and the AD5663R-5 uses 2.5 V. In both cases the full-scale output is twice the reference voltage. An external reference can be used if better performance is required than that provided by the on-chip reference, or if different full-scale voltages are required. The external reference is connected to the dual purpose V_{REFIN}/V_{REFOUT} pin.

The voltage reference(s) for a data converter may also be the power supply(s). The power supplies in many electronic systems are well regulated and fixed, and can therefore be used as a voltage reference, particularly in applications which are low cost and/or do not require very high conversion accuracy and precision. However, it is unlikely that the power supply will achieve the voltage reference quality of a good dedicated reference device. Furthermore, the power supply may also not provide a convenient reference voltage, depending on the application.

Fig.4 illustrates an example of a supply-based reference in the case of a PIC microcontroller's internal ADC. The ADC has two references for the upper and lower full-scale voltages, which, independently in each case, may be either the relevant supply (AV_{DD} for the positive reference and AV_{SS} for the negative reference) or an external reference voltage. This is set up by writing to the relevant device configuration register (VCFG in Fig.4). PICs do not all have exactly the same configuration for their ADCs, so you need check the datasheets and family reference manuals for devices that might interest you. PICs often have on-chip voltages references, which could be used as the 'external' reference.

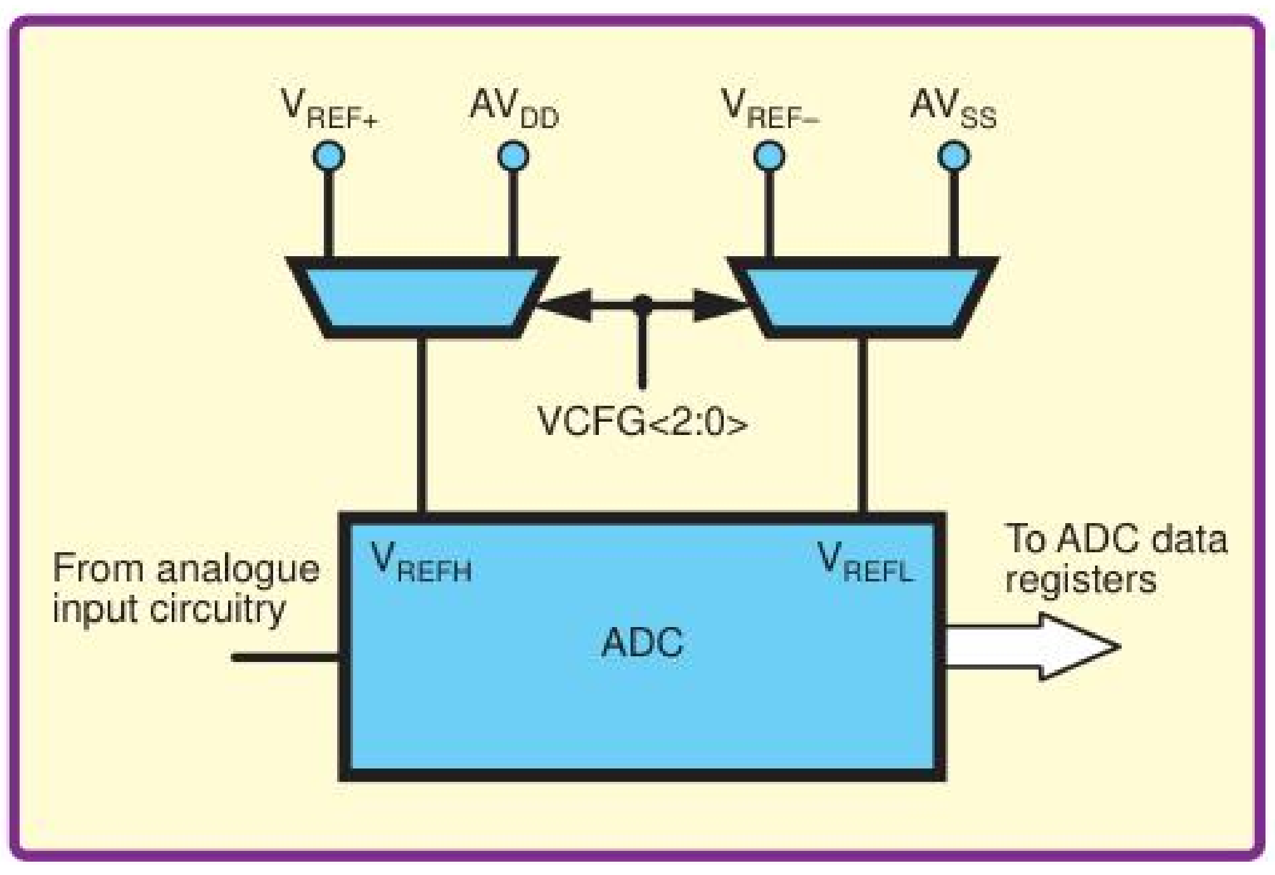

Fig.4. Part of the ADC circuitry of a PIC microcontroller showing reference voltage selection
(Based on PIC32MX5XX/6XX/7XX 32-bit Microcontroller Family Data Sheet, **www.microchip.com**)

Forms

Returning to the two forms of reference shown in Fig.3, the simplest form of two-terminal reference is a Zener diode (reverse biased into the breakdown region), or even a standard diode forward biased to give around 0.7V (see Fig.5). More sophisticated two-terminal regulators contain on-chip circuitry to compensate for the inadequacies of these individual devices. Three-terminal references are similar to linear regulators (not switching, because that produces too much noise) but are designed to produce an accurate and precise output rather than deliver significant amounts of power. We will discuss reference circuits in more detail next month.

Accuracy and precision

We have used the terms 'accuracy' and 'precision' a few times so far. These are important and, crucially, *different* concepts in measurement science; however, this not always understood because in everyday usage their meanings may overlap. Accuracy and precision relate directly to important characteristics of voltage references, so it will help to define them before looking at key datasheet parameters for these devices. As already indicated, many electronic measurement and signal generation instruments depend on voltage references for their accuracy and precision because voltage references are critical to the effectiveness of ADCs and DACs.

In measurement, the term 'accuracy' (at least traditionally – we'll come back to this) is about how close the measured value is to the true value of the quantity being measured. Typically, this is defined statistically, that is a large number of measurements are made of the same true value, and then 'accuracy' is defined as the difference between the true value and the average measured value. Thus, accuracy represents the size of any systematic error in the measurement. The term 'precision' is again defined in terms of multiple measurements and depends on the closeness of measurements to each other when measuring the same true value. Thus, 'precision' is related to random errors in the measurement process and statistically to the standard deviation of the measurement data.

Fig.6 shows the classic way of illustrating the difference between accuracy (defined as above) and precision (although this approach is not liked by everyone). This uses a target in which the bullseye represents the true value being measured and the points where shots have hit represent the measured values. In the best case (both accurate and precise) the hits

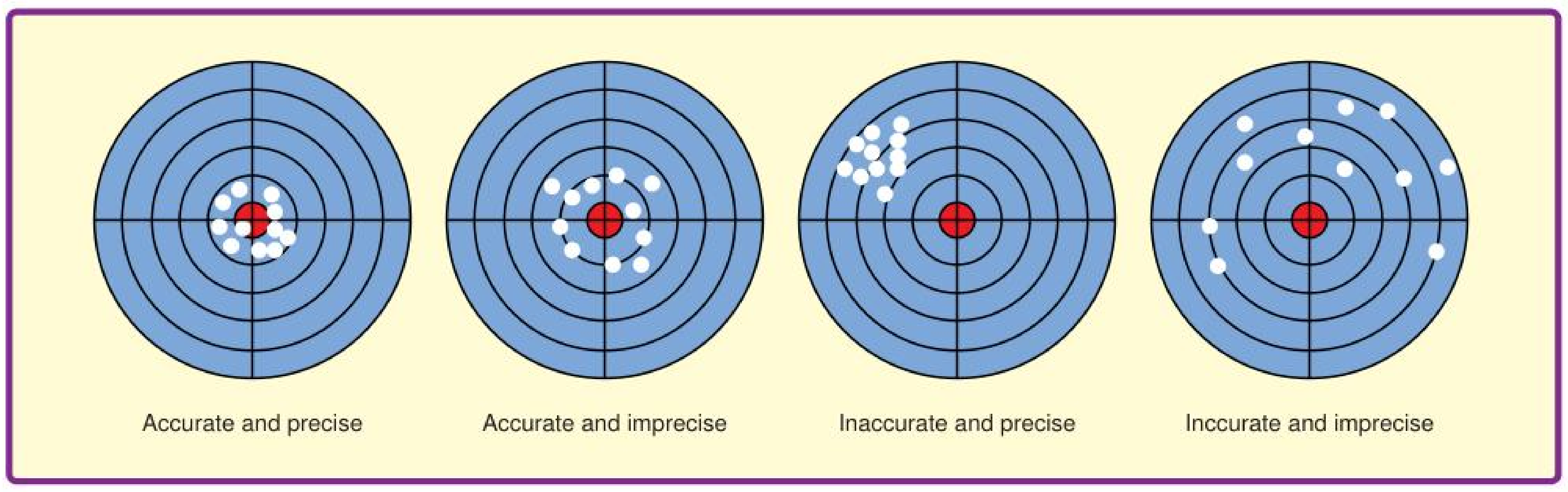

Fig.6. Classic illustration of the definition of accuracy (trueness) and precision using target grouping. The 'hit' locations indicate the measured values and the bullseye is the true value of the quantity being measured. The term 'accuracy' may be replaced by 'trueness'

are all clustered close to the bullseye. Precise, but inaccurate measurements are closely clustered, but away from the bullseye. Accurate but imprecise measurements are evenly, but more widely spaced around the bullseye.

Fig.7 shows a different illustration of the four cases in Fig.6. Here, the many measurements are plotted as a histogram (number of measurements showing a particular value plotted against the range of values measured). We assume that the number of measurements approaches infinity, so that the histogram becomes a smooth curve called a 'probability density function'. The graphs have the well-known 'bell curve' shape, also known as the 'normal' or 'Gaussian' distribution. The peak of the curve is the average (mean) value of the measurements and so its distance from the true value is the accuracy of the measurement. The spread of the curve indicates the precision; a narrow peak shows that all the measurements are close to the same value – a precise measurement.

Trueness

The issue of interpreting words such as 'accuracy' and 'precision' becomes more complex if you are trying to be as consistent as possible across multiple languages. A document from the International Organization for Standardization (ISO 5725, 1994) says that the term 'trueness' should be used instead of accuracy, as defined above. This is also adopted by the International Bureau of Weights and Measures (BIPM from the French Bureau International des Poids et Mesures) in their International Vocabulary of Metrology (VIM, initials again from the French version). According to ISO 5725 and VIM, the term 'accuracy' should be used in relation to the closeness of a single measurement to the true value (not the mean, as defined above). The problem with this is that it is not universally adopted. If you are interested in the complexities of grappling with these terms and how best to explain them, have a look at the 'talk' tab (not the main article) of the Wikipedia page on 'Accuracy and precision' – **https://en.wikipedia.org/wiki/Accuracy_and_precision**

Parameters

Key datasheet parameters for voltage regulators are: the output voltage, the tolerance or initial accuracy, the temperature coefficient, the output noise and the operating current. There are also parameters relating to operating conditions/loading – output resistance, capacitances, load regulation (for three-terminal devices).

Voltage reference output voltages tend to be in 'round' numbers and common supply values (1.8, 2, 2.5, 3, 3.3, 5…) and powers of two for use with ADCs and DACs (1.024, 2.048, 4.096…). Operating current is obviously important in low-power applications, but another factor to consider is that the lowest noise references tend to require much higher operating currents.

Initial accuracy or tolerance is about how close the reference voltage is likely to be to a specified value at a given fixed temperature (typically 25°C). The term 'tolerance' makes sense because it relates to the ability of the manufacturing process to deliver devices at the specified value. Initial accuracy, or tolerance, is usually expressed as an absolute voltage or a percentage of the specified voltage. Typical accuracy values for voltage reference ICs range from about 0.05% to 2%. Initial accuracy may seem to be very important; for example, when designing a high accuracy digital volt meter, but it is not necessarily the most important parameter if calibration is a possibility. In designs where high quality calibration is impossible, or inconvenient, or too expensive, initial accuracy of the reference may be more important.

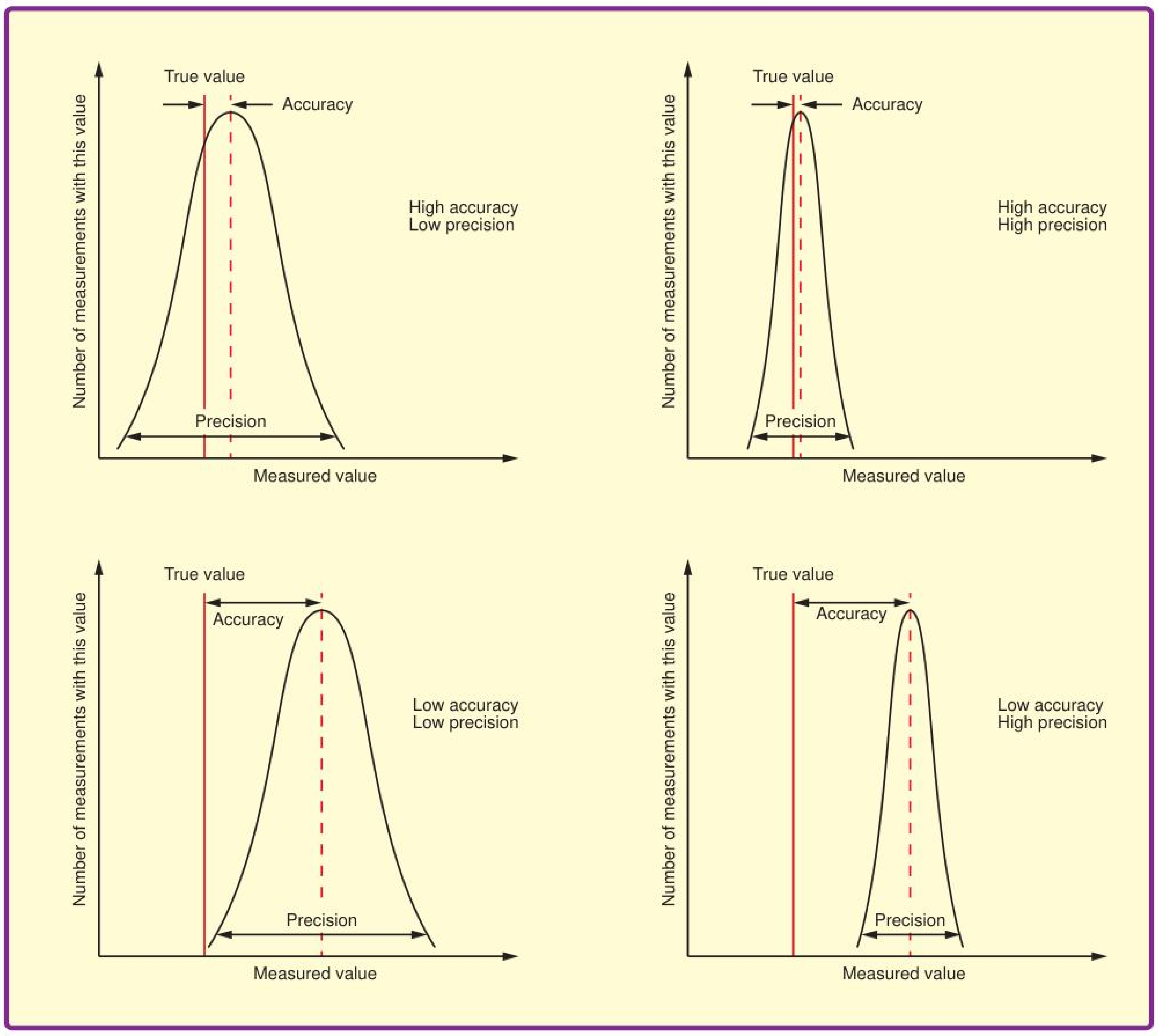

Fig.7. Statistical view of accuracy (trueness) and precision. A large number of measurements are made and the histogram or probability density function of the data is plotted. Accuracy and precision improve as the indicator distances labelled on the graphs decrease

An uncalibrated measurement system, which depends on a voltage reference will have an accuracy (traditional meaning, or VIM trueness) which depends on the reference's initial accuracy or tolerance. However, calibration removes much of this systematic error. The crucial parameters for a voltage reference once a system is calibrated are first, the level of instantaneous random variation in the reference value, which will directly affect the system's precision (as defined above); this is dependent on the amount of noise output from the reference. Second, how constant the voltage reference stays with changes in environment (particularly temperature) and with the passage of time. This will determine how well the system holds on to its calibrated accuracy.

Effects of temperature

As we indicated at the start, voltage reference variation with temperature is particularly important in high performance measurement applications. This is specified as the temperature coefficient (often shortened to 'tempco') in units of ppm/°C (parts per million per degree Celsius). Typical values for most reference ICs range from about 2 ppm/°C to 50 ppm/°C, but better performance is available from a few devices (which of course tend to cost more).

Care should be taken to check the range of temperatures over which tempco is specified and the linearity or otherwise of variation with temperature. A specification in terms of ppm/C may seem to indicate that the voltage linearly varies with this slope over the operating range, with the maximum and minimum voltages occurring at either end of the temperature range. However, this is often not the case, particularly for references will low tempcos. These often have very nonlinear variations of output voltage across the operating temperature range, with one or more peaks in the curve (so the variation of voltage with temperature is both positive and negative at different points).

Voltage reference tempcos are often specified by finding the difference between the maximum and minimum voltages ($V_{max} - V_{min}$), wherever these occur in the temperature range, and dividing by the temperature range ($T_{max} - T_{min}$) to give a ppm/°C figure. This approach is called the 'box method'. One problem with this is that it may overestimate voltage variation for a device operated over a smaller range than that for which the tempco was calculated.

Another temperature-related characteristic is thermal hysteresis. This is the shift in output voltage (usually in ppm) due to taking the device through a change in temperature (often well below and above ambient) and bringing back to the original temperature (possibly over a number of such cycles). Ideally, the output will be the same once the original temperature is restored, but this is not the case due to the effect of stresses on the chip caused by the heating and cooling. This kind of thermal cycling occurs during soldering and may potentially degrade initial accuracy.

Noise and drift

Noise occurs on the output of voltages references, just as it does for all electronic circuits. It is specified in μV/√Hz (microvolts per root Hertz) over a stated bandwidth. We discussed noise in detail in *Circuit Surgery* a few months ago, so refer to that for more details on how it is defined (*EPE*, August-September 2015). Usually, a voltage reference's noise is specified over two bandwidths, low (0.1 to 10Hz) and high (10Hz to 10kHz). The high frequency noise is relatively easy to deal with using a capacitor at the reference output (see Fig.3), although some systems may use more sophisticated filters. Low frequency noise is more of a problem because it is harder or less practical to remove. Noise from the reference will cause random errors in ADC and DAC outputs, reducing system precision.

In terms of the passage of time, the performance of references is described by its 'long-term stability' in units of ppm/√kh (parts per million per root kilo hours, where a kilo hour is 1000 hours, which is about six weeks). Long-term drift in voltage regulators tends to reduce, in a logarithmic manner, as time goes on, which is reflected in the use of the √kh units. However, some devices are specified in terms of ppm/kh (parts per million per kilo hours).

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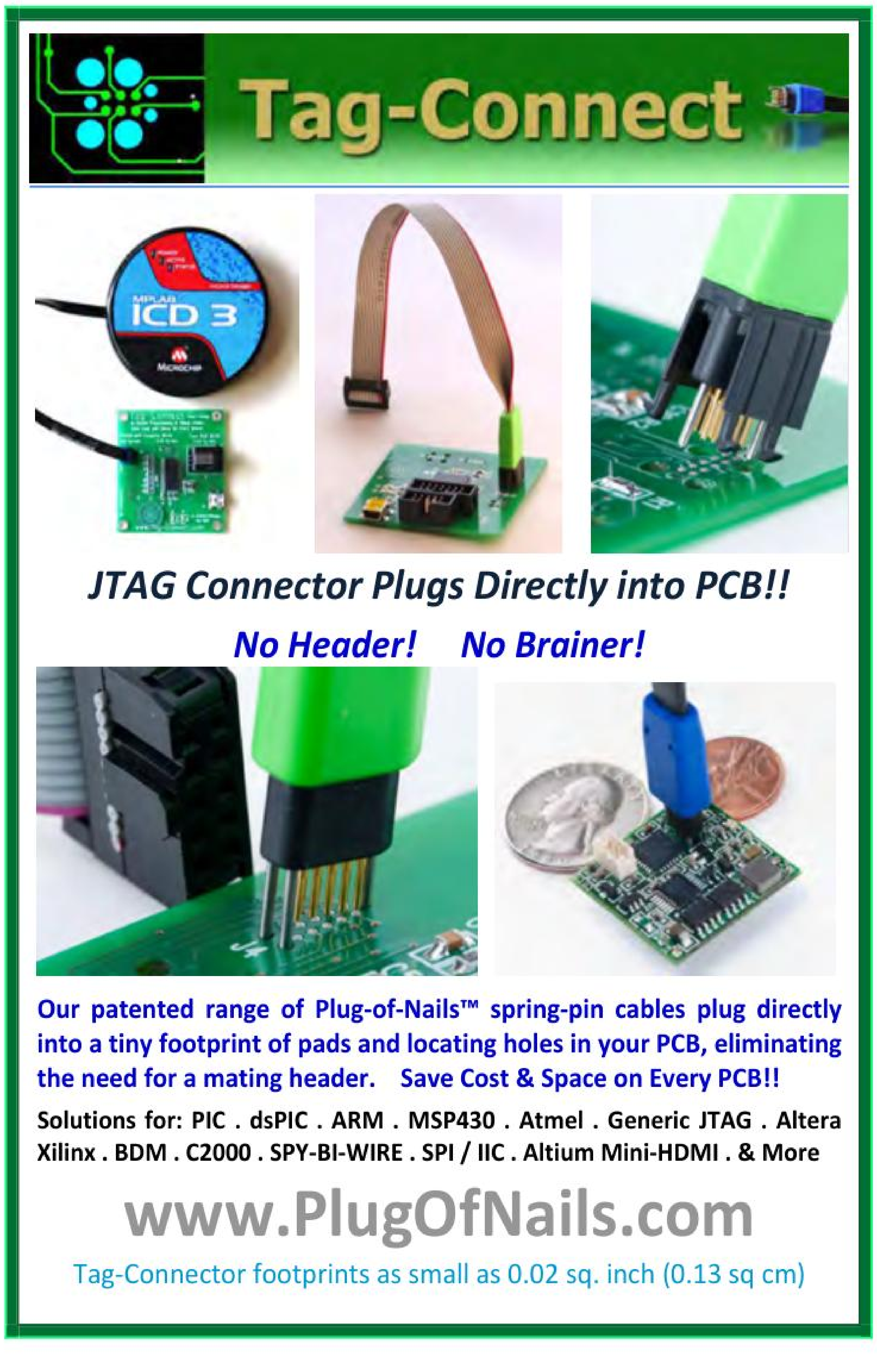

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AUDIO OUT

By Jake Rothman

Speaking volumes – Part 4

Active volume control

Last month, I showed how headroom and noise were in conflict in pre-amps using passive volume controls. Do we put the maximum fixed gain required before or after the passive volume control? An active volume control circuit solves this dilemma. Only the gain needed is used by arranging the volume pot to vary the actual amplification. The simplest way of doing this is to use an op amp with a log pot in place of the feedback resistor in an inverting circuit, illustrated in Fig.1. It provides all the advantages of an active control, but its gain is dependent on the absolute value of the track resistance (unlike a passive potentiometer) so the gain could be 20% out between the channels at maximum gain.

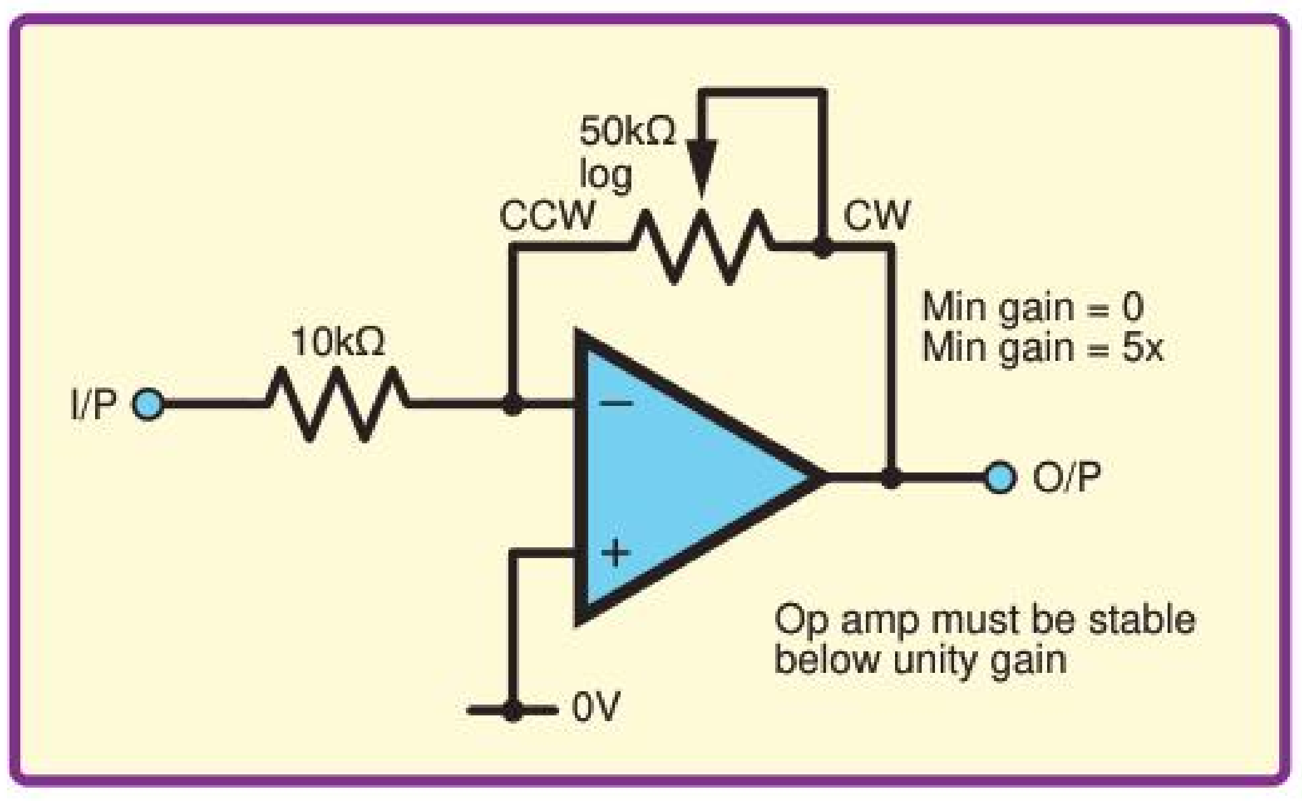
50kΩ
log
CCW
CW
10kΩ
I/P
O/P
Min gain = 0
Min gain = 5x
Op amp must be stable below unity gain
0V

Fig.1. Simple active volume control. A log pot used as the feedback resistor in an inverting op amp circuit.

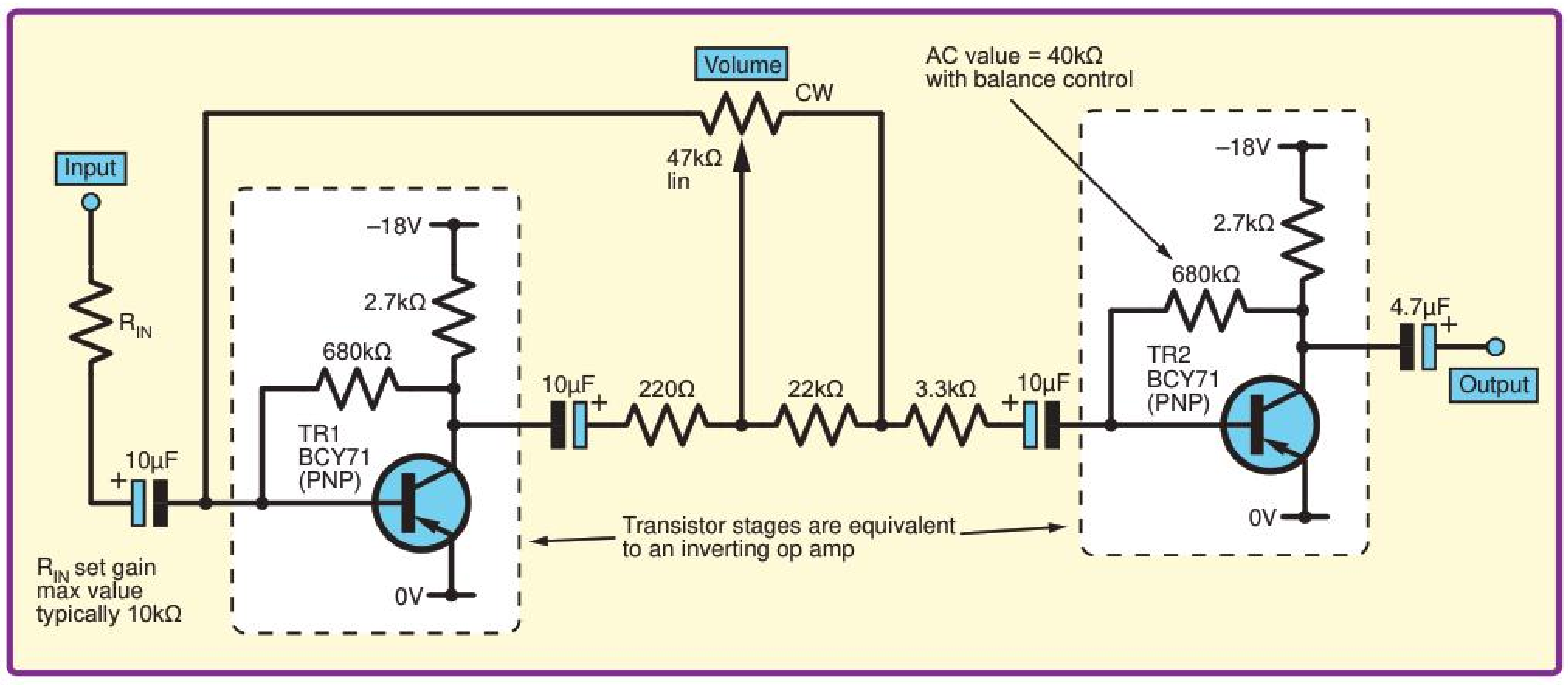
Volume
CW
47kΩ
lin
AC value = 40kΩ
with balance control
Input
R_{IN}
–18V
2.7kΩ
680kΩ
TR1
BCY71
(PNP)
10µF
10µF
220Ω
22kΩ
3.3kΩ
10µF
–18V
2.7kΩ
680kΩ
TR2
BCY71
(PNP)
4.7µF
Output
0V
0V
Transistor stages are equivalent to an inverting op amp
R_{IN} set gain max value typically 10kΩ

Fig.3. In the Stan Curtis design for the Cambridge P60 integrated amplifier, the volume control used a linear pot. This was possibly the first use of an active log-law synthesising volume control in production.

This does give the nice smooth characteristic down to zero of a traditional log pot, but only works well in stereo with *accurate* parts, such as expensive Panasonic pots. Since this is an op amp inverting stage, the maximum gain can be simply reduced by increasing the input resistor. Although the circuit is inverting, the phase can normally be flipped back at some other point in most systems, such as with a Baxandall tone control, which is also inverting. The non-inverting op amp configuration is not suitable, since its gain cannot go down to zero (minimum gain = 1).

This inverting amplifier technique was used in Douglas Self's April 1979 *Wireless World* design shown in Fig.2. This was a unique discrete design, which was very cost effective when 5534 op amps cost £5 each. Self's design used a bootstrapped cascode for lower distortion. (A similar gain block was used in the 1976 Radford ZD22 pre-amp running at 60V.) I used to build the Self circuit with tantalum capacitors since their low leakage currents minimised the pot scratching if the circuit had not been used for a while. The high distortion of tantalum capacitors did not appear since there was inadvertent capacitor distortion cancellation because the capacitors were in the feedback loop.

The transconductance of TR1 was boosted by a resistor supplying extra current. This allowed the TR2 to be run at a lower current, permitting a higher total collector load resistance, further

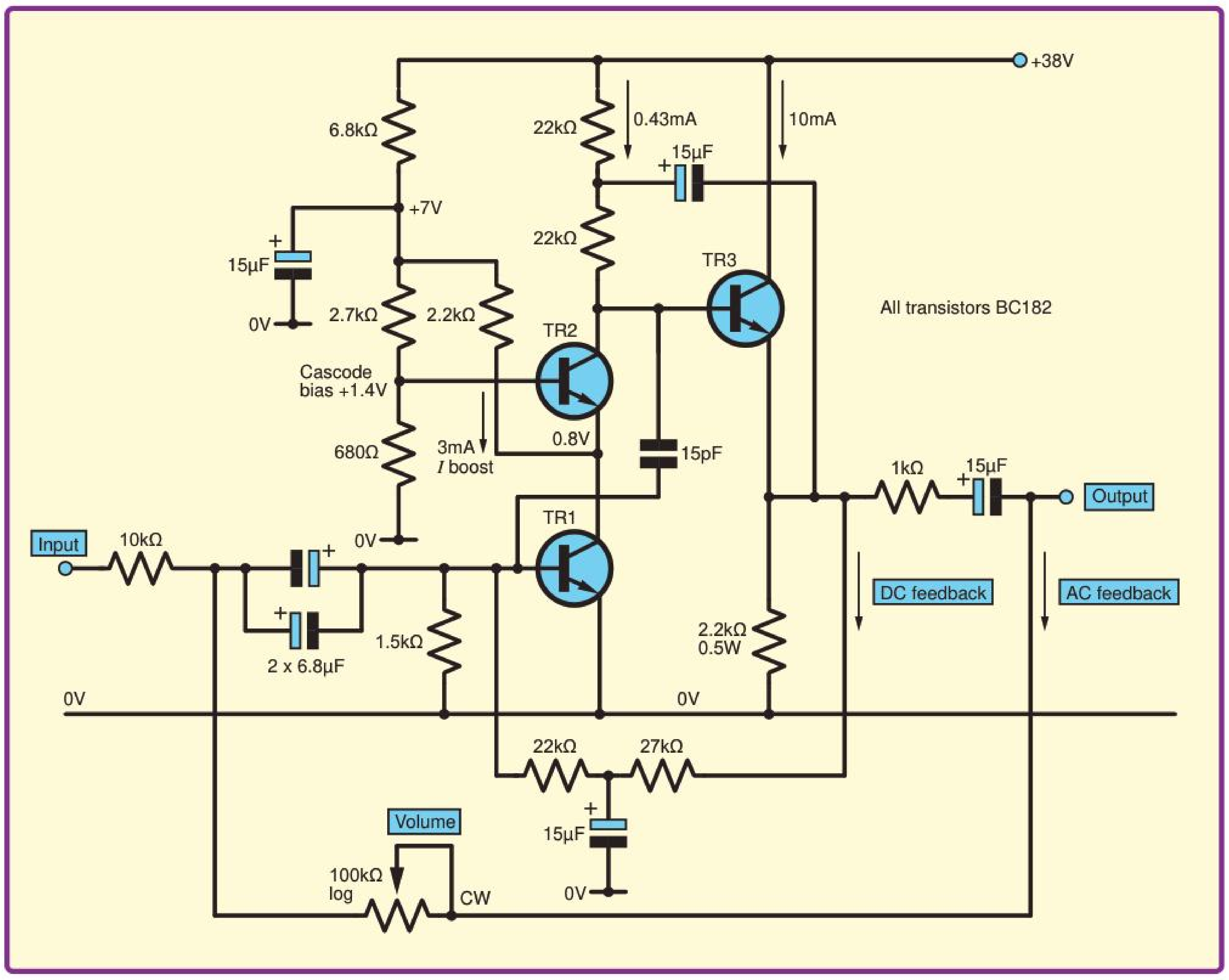
+38V
6.8kΩ
22kΩ
0.43mA
10mA
15µF
+7V
15µF
0V
22kΩ
TR3
All transistors BC182
2.7kΩ
2.2kΩ
TR2
Cascode bias +1.4V
680Ω
3mA
I boost
0.8V
15pF
1kΩ
15µF
Output
TR1
Input
10kΩ
0V
2 x 6.8µF
1.5kΩ
DC feedback
AC feedback
2.2kΩ
0.5W
0V
0V
22kΩ
27kΩ
15µF
0V
Volume
100kΩ
log
CW

Fig.2. A discrete version of Fig.1 from Douglas Self's pre-amp in Wireless World *(April 1979). Only the input capacitor needs be a low distortion type. I used to put two 6.8µF tantalums in reverse parallel.*

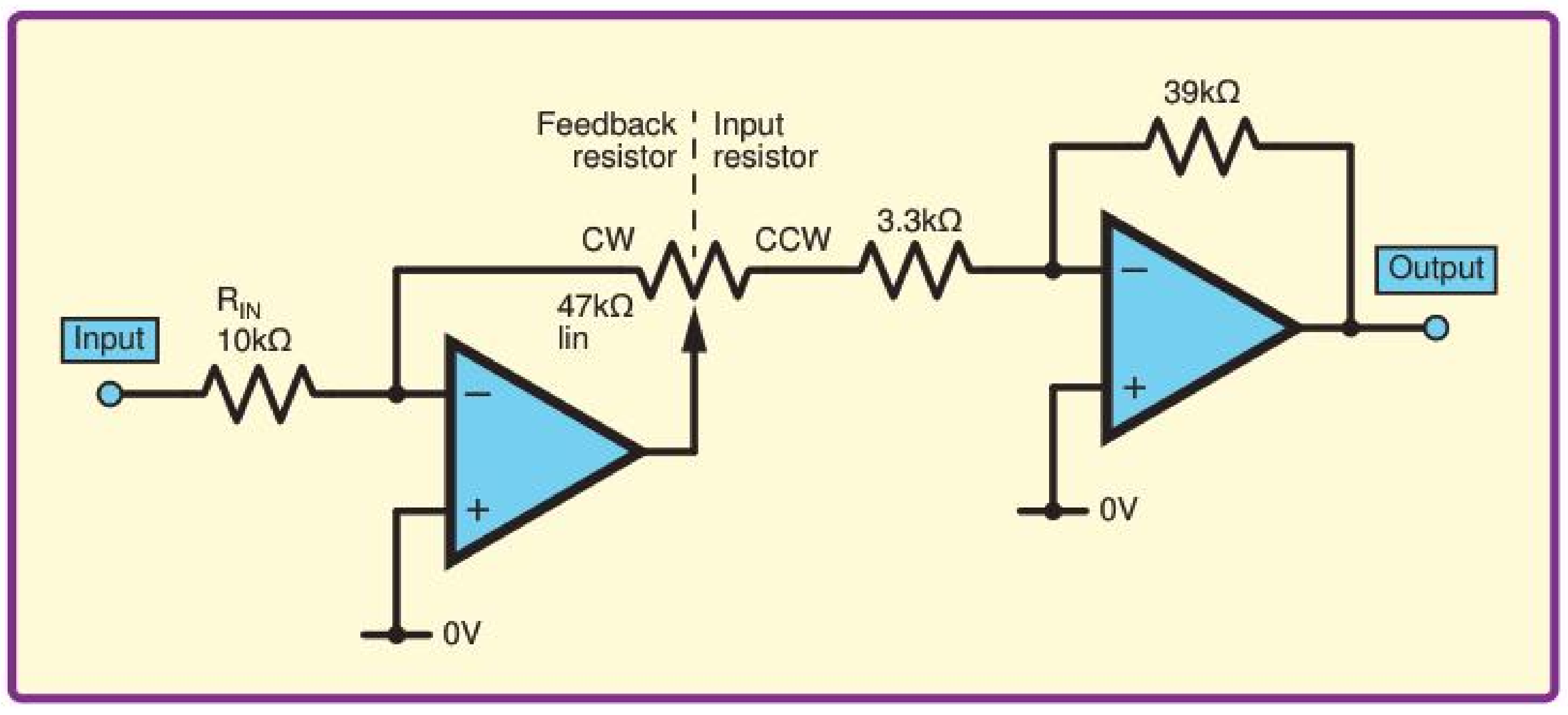
Feedback resistor
Input resistor
39kΩ
CW
CCW
3.3kΩ
Output
RIN 10kΩ
47kΩ lin
Input
0V
0V

Fig.4. The P60 circuit in 'op amp' form, illustrating how a log action on the linear volume pot is generated by the track sections on the clockwise and counter-clockwise sides of the wiper; both increasing the gain together as the knob is rotated.

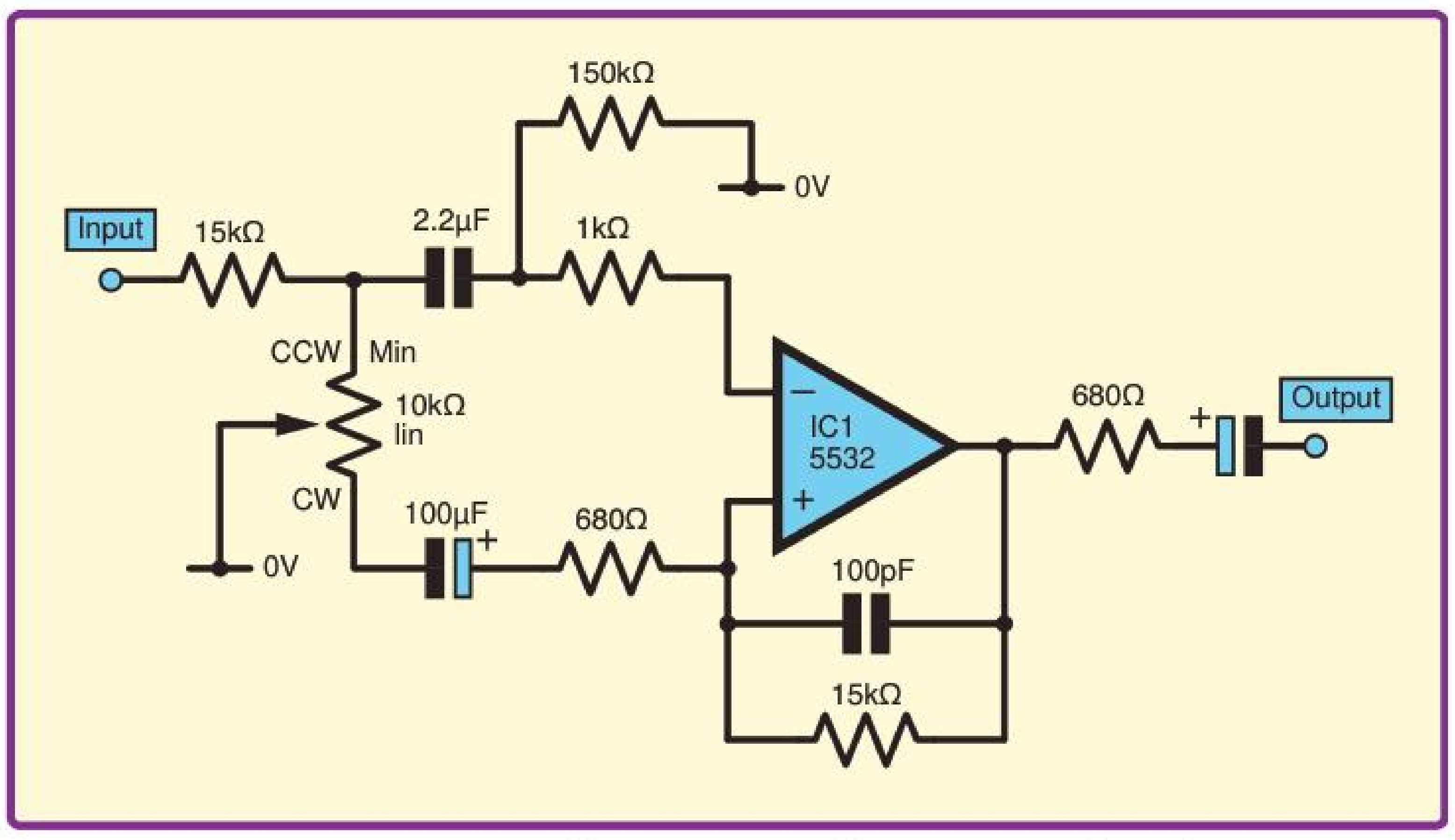
150kΩ
0V
Input
15kΩ
2.2µF
1kΩ
CCW
Min
10kΩ lin
CW
0V
100µF
680Ω
IC1 5532
680Ω
Output
100pF
15kΩ

Fig.5. 'Swinging-input' volume control circuit. Like the circuit in Fig.4, this circuit again uses both sides of the track. One provides attenuation on the input, the other provides gain on a non-inverting stage, to give a log law.

increasing the gain. This circuit dodge was described in TK Hemingway's *Circuit Designer's Handbook* (2nd ed, p229). This is an excellent reference on discrete design – well worth seeking out.

One failing of some active gain control circuits is that a bit of dust on the track lifting the wiper can result in the gain going very high, resulting in unpleasant noise. The Self pre-amp in its old age and the circuit in the Cambridge P60 amp (see Fig.3) suffered from this, exacerbated by unsuitable Omeg pots. A separate DC feedback path must be provided around the amplifier if the pot is AC coupled (which is necessary to avoid DC through the pot causing rotational noise). If this isn't done the op amp will hit the rails and may even rip out expensive speaker cones.

Steve Dove's series, 'Designing a Professional Mixing Console', in *Studio Sound* magazine in 1980, had a serious look at gain controls and pots in feedback loops – see: **www.collinsaudio.com/Prosound_Workshop/Steve_Dove_Console_Design.pdf**

Douglas Self's book, *Small Signal Audio Design*, published in 2010, then took it to the current state of the art of analogue audio.

Active volume controls also provide many solutions to the problem of obtaining accurate log pots and allowing

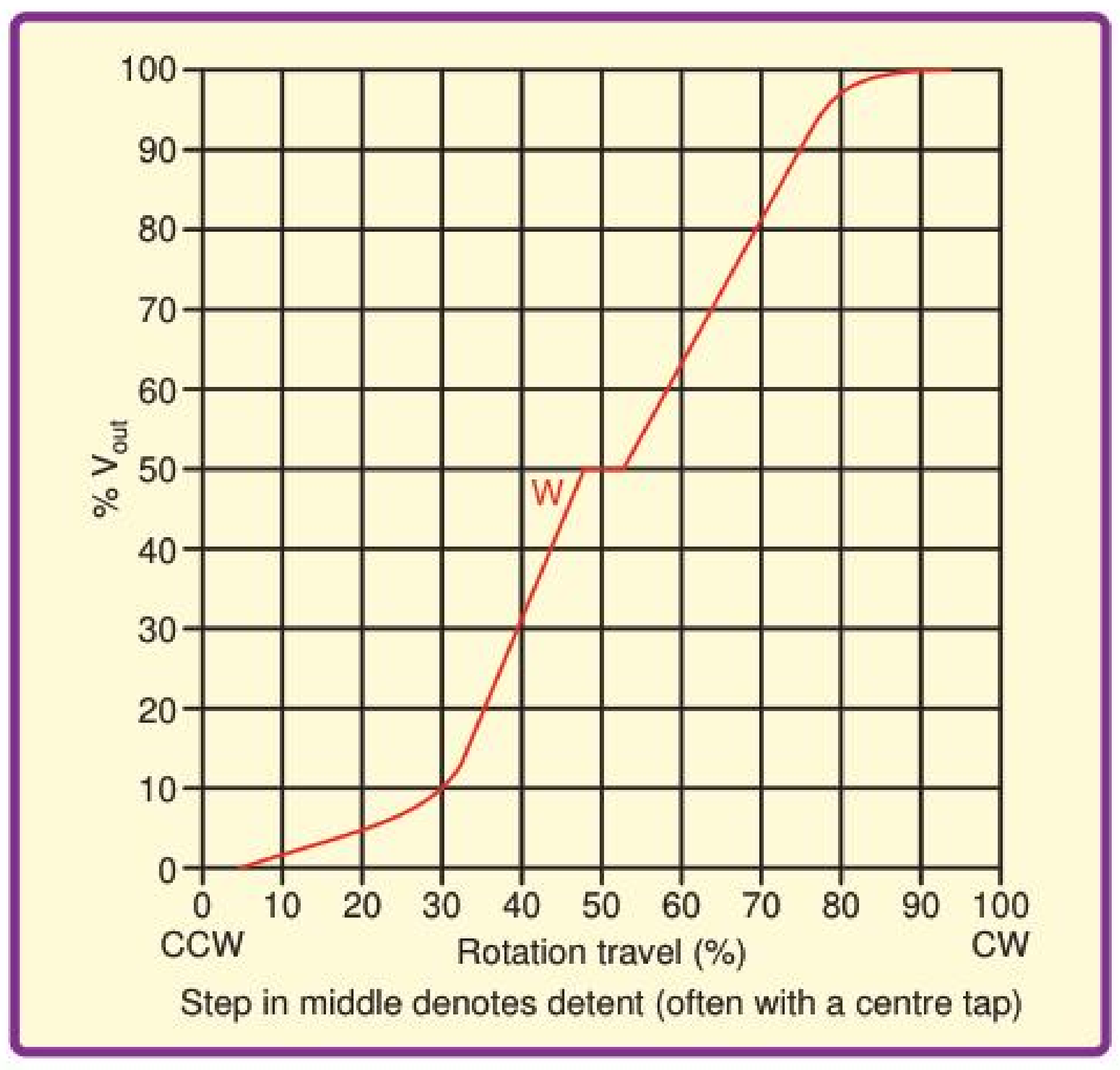

Fig.6. Graph of a potentiometer 'W-law' often used in 'swinging input' equaliser boost/cut controls.

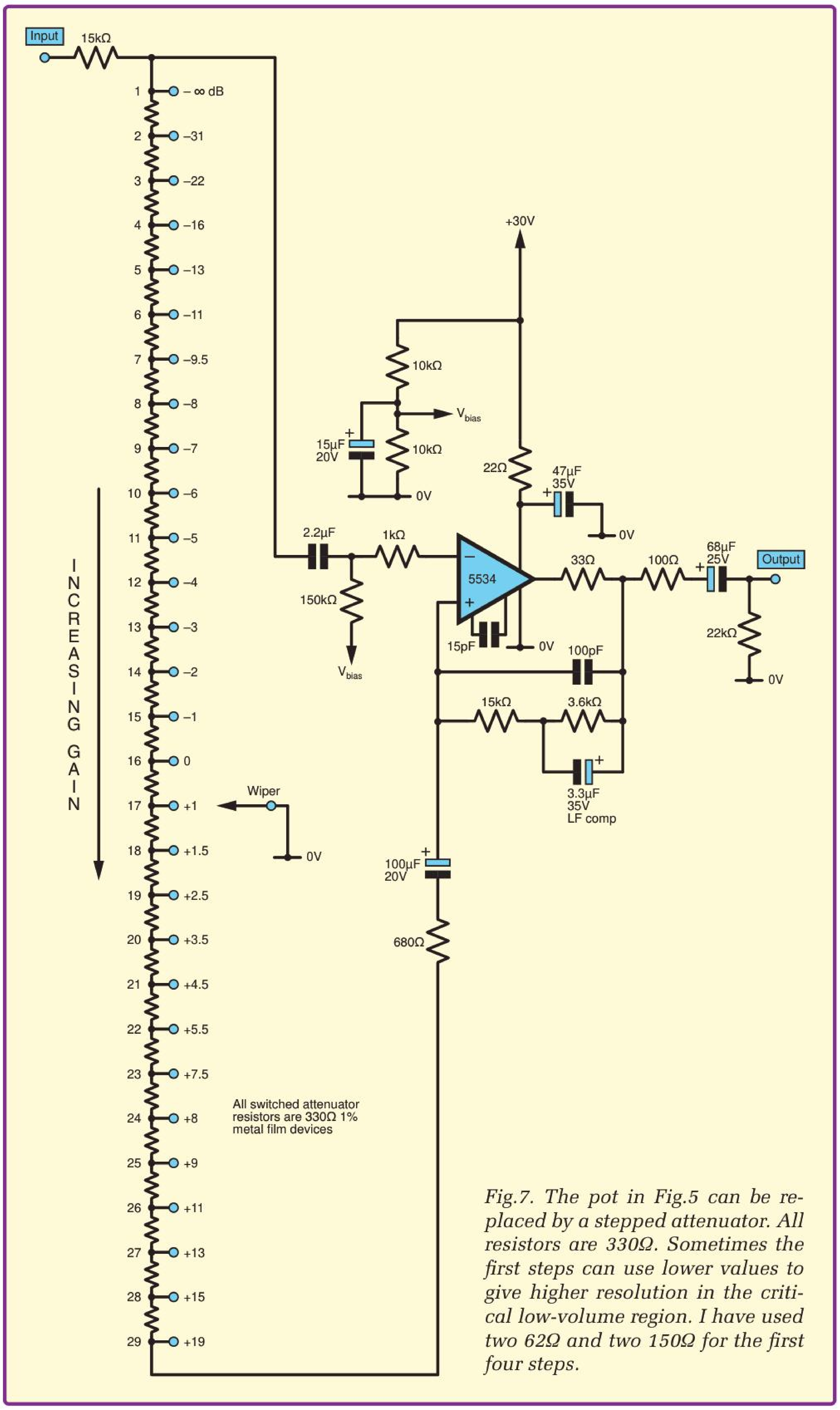
Input
15kΩ
1 – ∞ dB
2 –31
3 –22
4 –16
5 –13
6 –11
7 –9.5
8 –8
9 –7
10 –6
11 –5
12 –4
13 –3
14 –2
15 –1
16 0
17 +1
18 +1.5
19 +2.5
20 +3.5
21 +4.5
22 +5.5
23 +7.5
24 +8
25 +9
26 +11
27 +13
28 +15
29 +19
INCREASING GAIN
Wiper
0V
+30V
10kΩ
Vbias
15µF 20V
10kΩ
0V
22Ω
47µF 35V
0V
2.2µF
1kΩ
150kΩ
Vbias
5534
15pF
0V
33Ω
100Ω
68µF 25V
Output
22kΩ
0V
100pF
15kΩ
3.6kΩ
3.3µF 35V LF comp
100µF 20V
680Ω
All switched attenuator resistors are 330Ω 1% metal film devices

Fig.7. The pot in Fig.5 can be replaced by a stepped attenuator. All resistors are 330Ω. Sometimes the first steps can use lower values to give higher resolution in the critical low-volume region. I have used two 62Ω and two 150Ω for the first four steps.

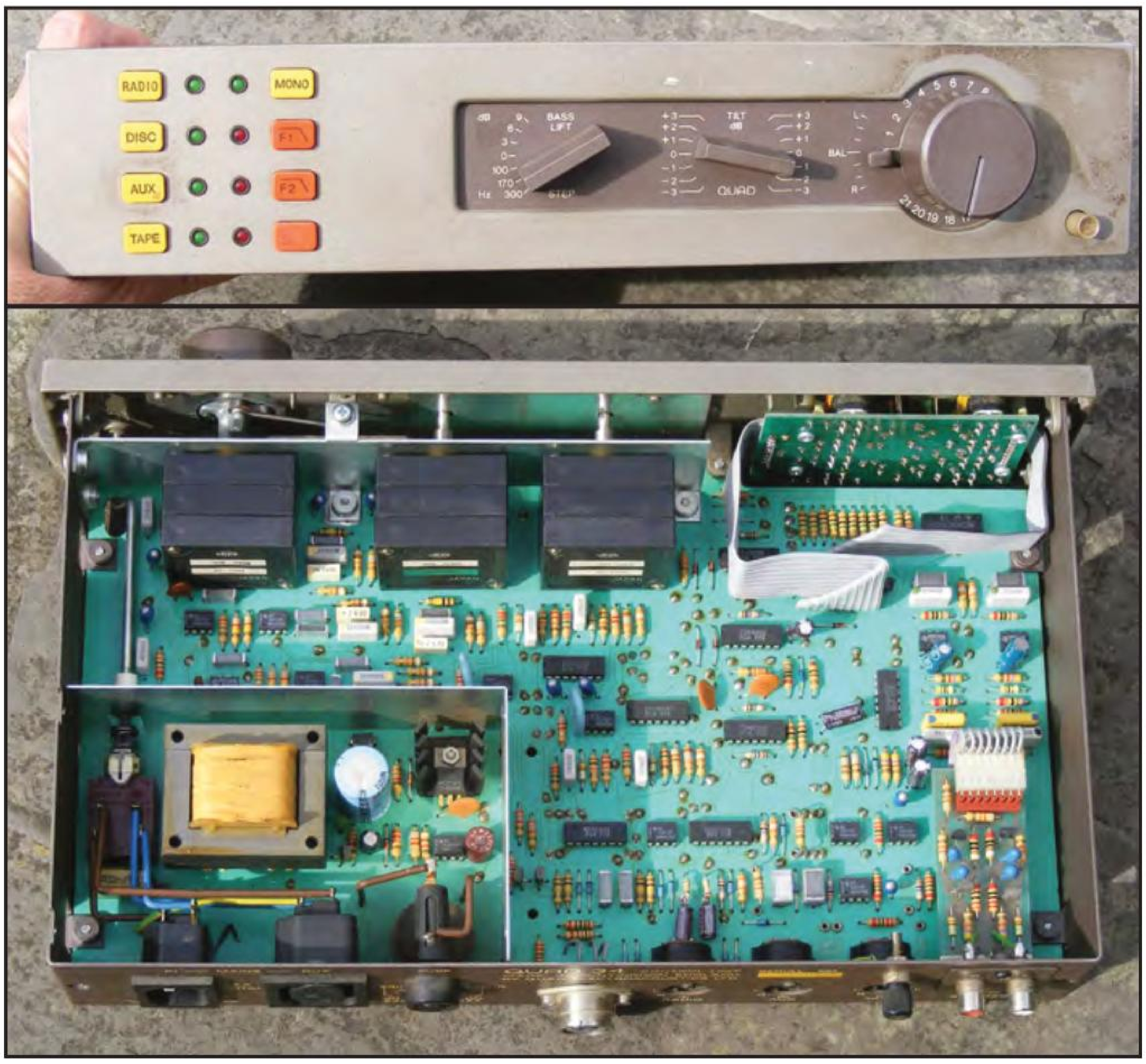

Fig.8 (top) The Quad 34 pre-amp, a classic late-70s design – note the stepped controls; (bottom) Quad 34 pre-amp internals – note the special Alps 'Black Velvet' controls.

the much more common linear type to be used.

Two-stage gain control

One way of converting a linear pot to give a log action is to split it into 'two resistor halves' at the wiper, one providing attenuation, the other controlling feedback, or using both halves in feedback loops (see Fig.4). There are a multitude of variations of this theme. Steve Dove popularised this in his microphone pre-amp by combining a non-inverting op amp circuit with an inverting one. This technique has the problem of not going to zero gain because of the non-inverting stage on the front. This is not a problem for mic gain controls and drive pots on Fuzz boxes, but is unacceptable for a pre-amp.

Redrawing the P60 volume control shows how there are two inverting 'op amp' circuits in series. The first half of the pot track is the feedback resistor of the first stage and the second half of the pot is the input resistor of the second stage, shown in Fig.4.

Swinging input circuit

This approach uses a mixture of attenuation on the input (which allows it to go to zero) and active gain on a non-inverting op amp circuit (Fig.5). This provides a very desirable combination of headroom and gain, which makes it difficult to cause overload at low volumes. It gives a gain/rotation curve that has an increased effect tending to jump at both ends. It is called swinging because it can be used to give a symmetrical boost/cut of say ±15dB with a suitable wiper resistor. When used as a volume control, the wiper is directly connected to ground to give full attenuation to zero. The circuit does make initial rotation errors apparent on the pot, which makes it undesirable for stereo. It is very popular as a boost/cut control in equalisers however. Here a special 'W-law' pot is often used with a centre detent, which flattens off the curve at both extremes of rotation, as shown in Fig.6.

Stepped active volume controls

For stereo, a stepped resistor ladder swinging input works very well, avoiding the initial mistracking problem of many dual/stereo pots. Most of the resistors can be the same value, apart from the low volume end of the pot rotation where they are smaller in value to deal with the ears' increased sensitivity at low volumes. The stepped attenuator is shown in Fig.7.

The Quad 34 Volume control

A unique system was used in the Quad 34 pre-amp (Fig.8 top) using a specially made Alps thick-film laser-trimmed 21 position stepped attenuator, shown in Fig.8 (bottom). I spent ages measuring the values because they weren't on the net, not even on Keith Snook's excellent site, **www.keith-snook.info**. The circuit is shown in Fig.9 and varies the input and feedback resistances of an inverting op amp simultaneously. This system worked very well since each gain step was optimised. (Note that the input needs to be attenuated for CD sources.) Unfortunately, the pre-amp suffered from the use of CMOS 4016/66 bi-lateral switches, which have one of the worst reliability records for audio semiconductors!

Baxandall volume control

The Baxandall active volume control is one of the most successful circuits because it is insensitive to the absolute

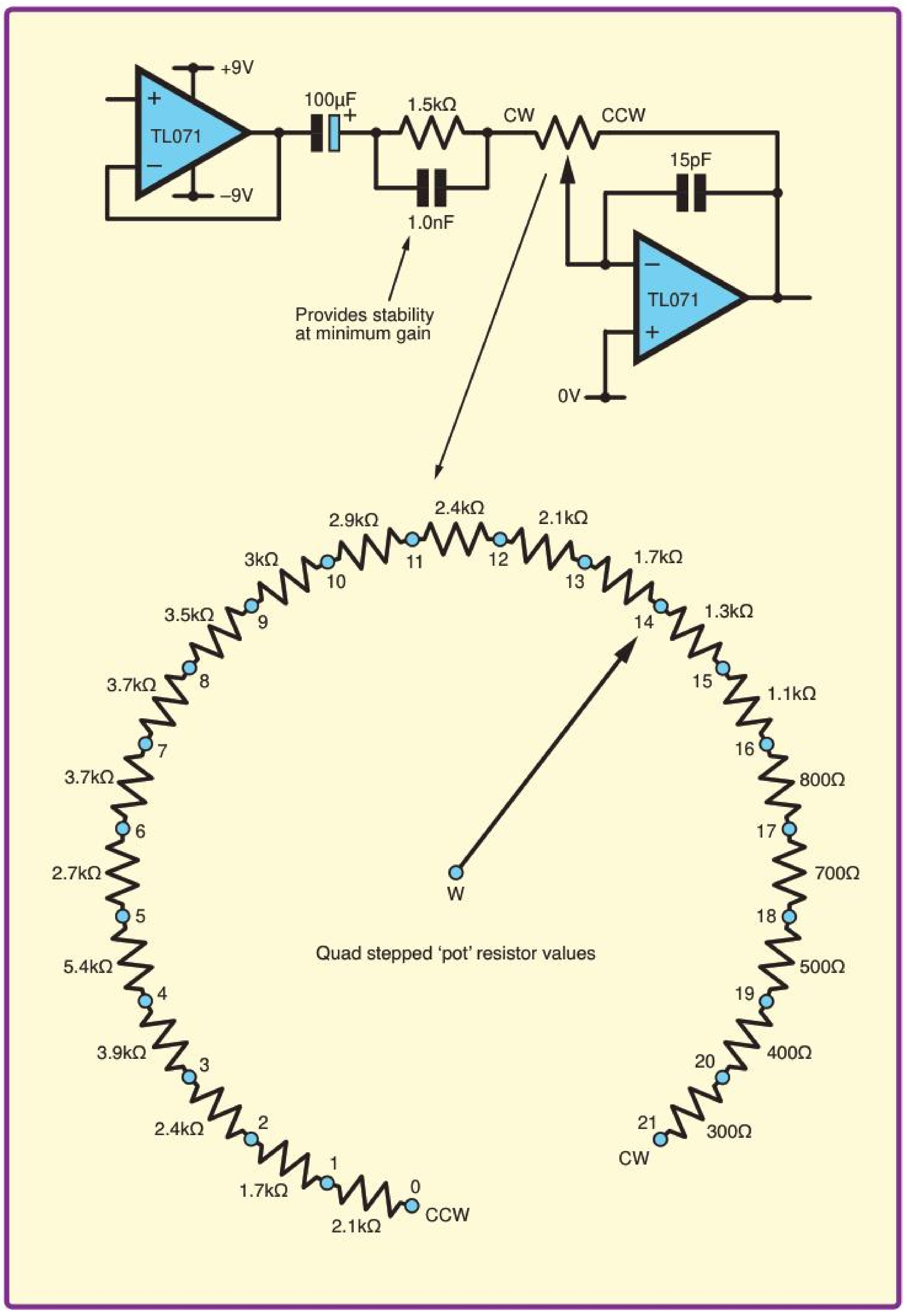

Fig.9. The Quad 34 active volume control – in the op amp circuit, the 'pot' is a stepped attenuator with unique resistor values.

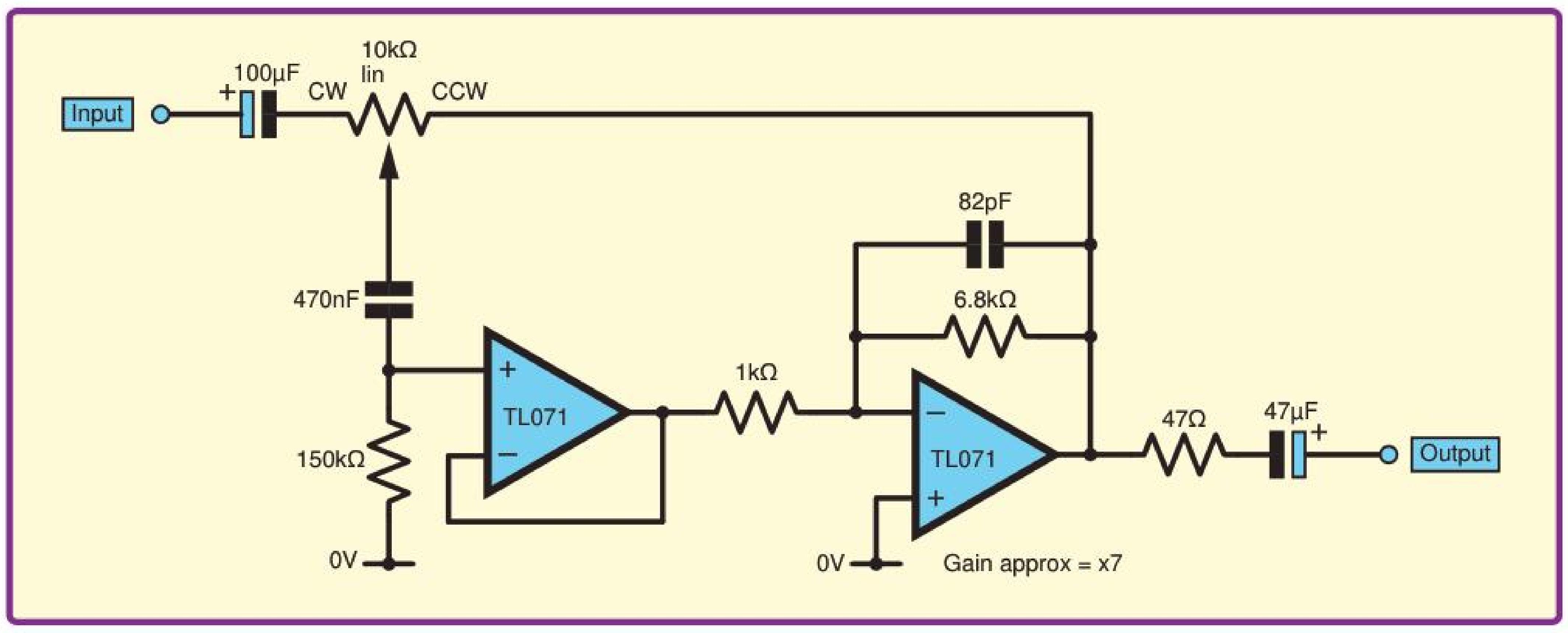

Fig.10. *The standard Baxandall active volume circuit, as used in the* Hi-Fi Stereo Headphone Amplifier *(*EPE*, October 2014). The absolute value of the track does not affect the gain, only the ratio of the two halves. The input impedance drops to one tenth of the pot value at max volume.*

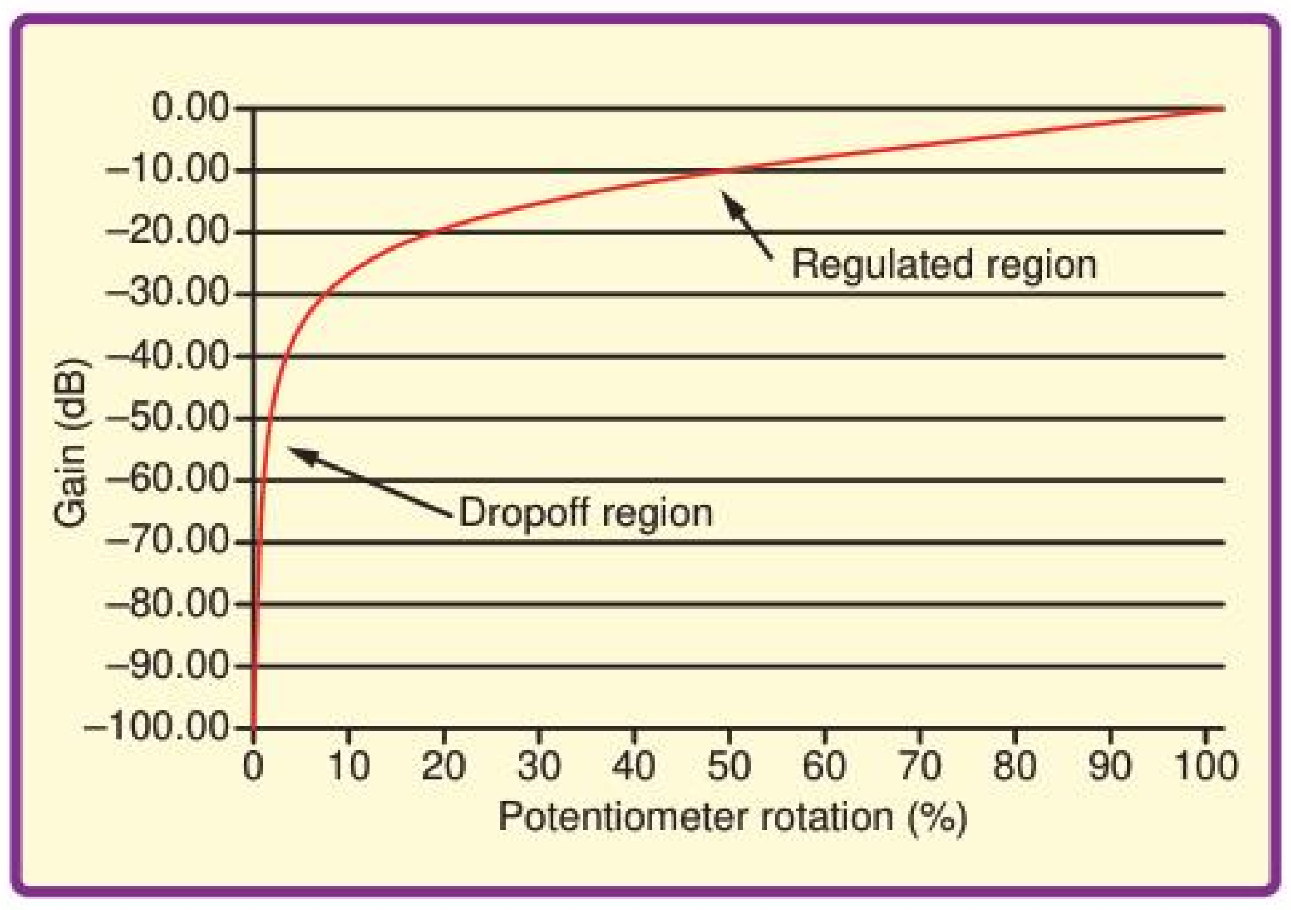

Fig.11. Gain vs rotation curve of the Baxandall volume circuit taken from a Texas Instruments application note. The curve of the variant circuit is almost the same.

track resistance value. Its gain is only dependent on the potentiometric ratio, like a normal passive volume control. The logging action is also quite good. It is not used very often because it appears complex and increases the amplifier count, which is a shame because op-amps are much cheaper than precision log pots. The circuit is fully discussed in Baxandall's article 'Audio Gain Controls' in *Wireless World*, October and November 1980. For those who don't have access to *Wireless World* back issues, which are an essential resource for audio designers, there's a site called **americanradiohistory.com** which hosts almost all of them.

The standard version of his circuit is given in Fig.10 which was used in the *Hi-Fi Stereo Headphone Amplifier* in *EPE* October 2014. It has also reappeared in an application sheet from Texas Instruments **www.ti.com/lit/ug/tidu034/tidu034.pdf** giving some useful plots (Fig.11) and a PCB design. The standard Baxandall has the disadvantage of an input impedance that is one tenth the pot value at maximum volume. This means an extra buffer is needed on the input end of the pot to prevent excessive loading of the source.

An obscure variant of the standard Baxandall volume control circuit outlined in the original article (p81 Fig.25) was the inspiration for my design, which I will explain next month. This had a floating input, which was a problem unless an input transformer was used. Later, Baxandall rearranged the circuit to avoid this, as shown in Fig.12 (from *The Audio Engineer's Reference Book*, Focal 1994). I found this circuit had a higher input impedance (9kΩ) with the same performance, thus saving an op-amp.

Next month we'll add some active volume enhancements and use Fig.12's Baxandall circuit topology in a unique high-voltage discrete pre-amp.

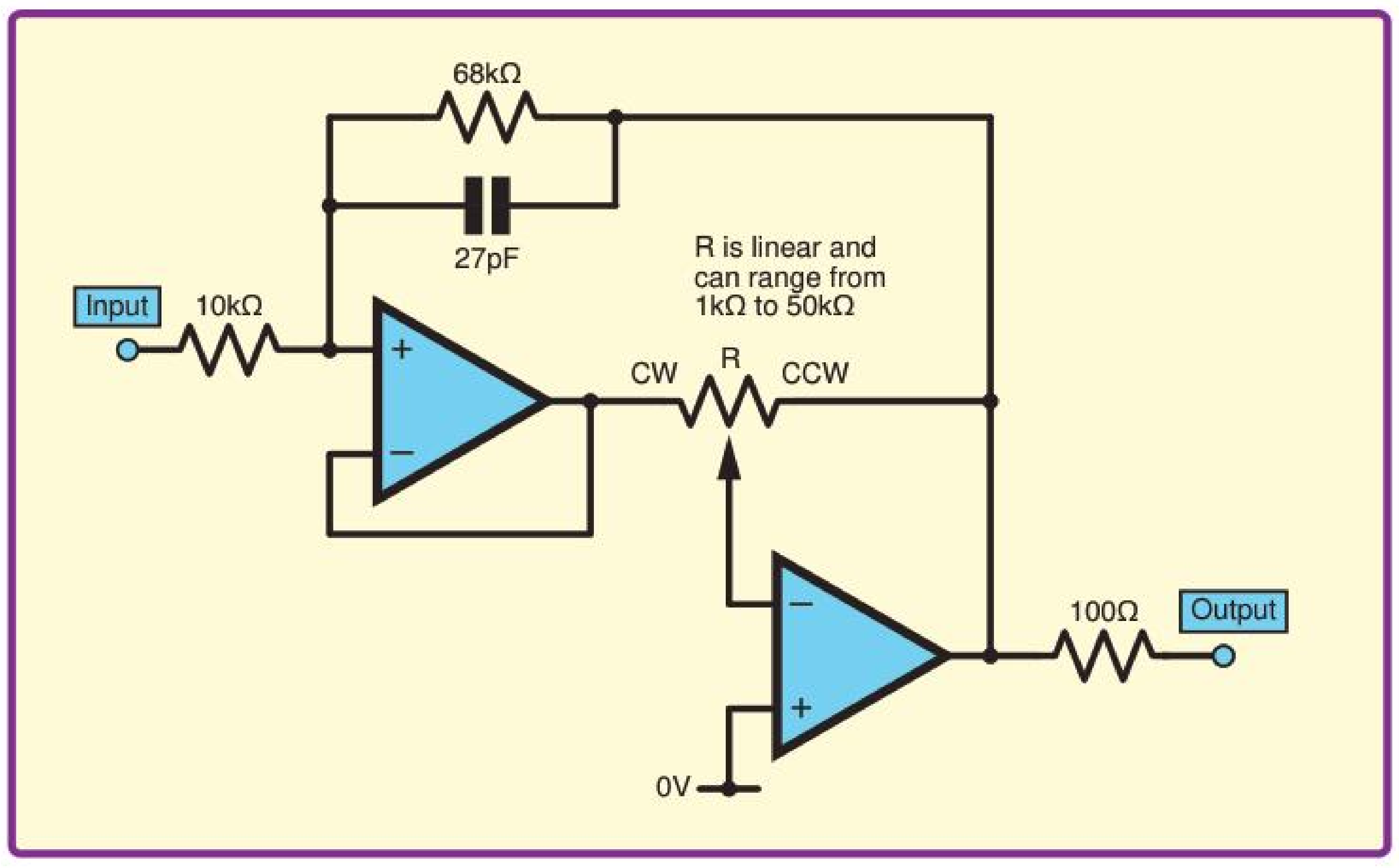

Fig.12. A variant of the Baxandall volume circuit – it has a higher input impedance, 9kΩ at max volume, 46kΩ half way and 75kΩ at minimum volume. This characteristic remains the same whatever the pot track value over the range 1kΩ to 50kΩ.

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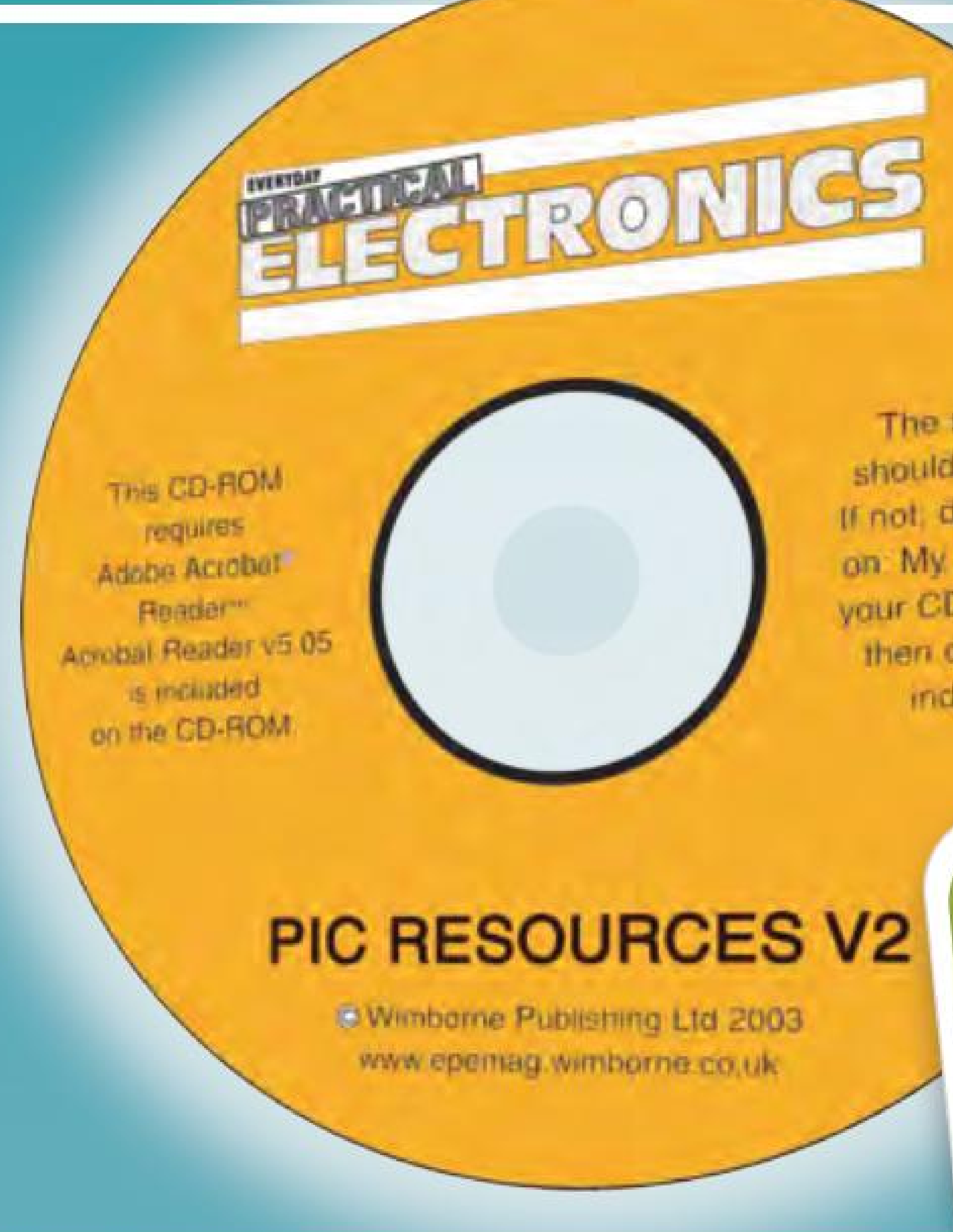
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All letters quoted here have previously been replied to directly

Email: editorial@wimborne.co.uk

☆ LETTER OF THE MONTH ☆

Jacob's ladder components

Dear editor
I read the *Jacob's Ladder* article (*EPE*, April 2014) and the 'all-time best-ever' coil is the so-called 'wasted spark' coil from a points-era motorcycle. This type of coil has two heavily insulated HT leads that come from opposite ends of the same secondary, the ratio is higher because the spark has to jump 2 × 0.025-inch gaps in series. These coils were used on twin cylinder machines with 360º crankshafts (but not ones with 180º cranks – those had two coils). There are two such coils on a four-cylinder engine, and three on a six-cylinder one.

I hope I'm not encouraging any delinquency, as most current motorcycles have electronic ignition that dumps a higher voltage onto the HT coil primary – these coils are far less suitable and may not even work in such a project. There are various breakers yards dotted around the country that will, no doubt, have some stock of points-era wasted spark coils, and as summer approaches there will be various motorcycle festivals and rallies with auto-jumble stalls. As far as I know, there weren't any wasted spark car coils, but the 80s era potted coils with closed-loop laminations may well work, but with only one HT lead – far less convenient for a Jacob's ladder.

For an 'ignition module' – a 555 only needs a high voltage MOSFET to do the job very nicely. Some time ago I developed a MOSFET TAC (transistor-assisted contact) for a small points-era motorcycle. My main source of suitable MOSFETs was the flyback SMPS in scrap CRT PC monitors; one particular 19-inch model had a very versatile 9A 900V device in the PSU, a rare beast – but 600V types are very easy to get hold of (and just about adequate). MOSFETS are easy to parallel, so the more usual 6A rating isn't a severe hardship. The motorcycle coils I experimented with did not use a ballast resistor – they were wound with PTC wire, at room temperature they draw about 8A and slowly sink to about 4A as they warm up.

The 555 oscillator can be tuned for the fiercest continuous arc at a dip in the LT current – the arc can damage and/or set fire to things, so some care is required. My experiments on the way to developing a MOSFET TAC led in various directions. The final design fitted to the machine used the MOSFET in a grounded gate configuration – the gate was connected to +12V, the drain to the coil LT and the source to the points. This solved one big problem that plagued just about every previous prototype – the LT winding is still ultimately in series with the points, so there is 'wetting current' to break through oxide and tarnish on the points, but the back EMF stops at the MOSFET drain, so no arcing and pitting on the points. Points 'wetting' had been a huge problem, as the puny generator on this small machine simply wasn't up to supplying a separate source of wetting current. The grounded gate configuration is the fastest way to switch a MOSFET (or a bipolar transistor for that matter) so the ignition pulses were very fast and clean. Even with the points capacitor to limit dV/dt while the points get far enough apart, there is some arc wasting energy, but the MOSFET TAC almost entirely eliminated that.

Ian Field, by email

Matt Pulzer replies:
Top tips – many thanks Ian. The Jacob's Ladder *project generated a affair amount of interest, so I think it is safe to say* EPE *readers enjoyed making their own spectacular electronic ozone machines! But please, if anyone out there wishes to experiment then do be safe, and if you are not sure what you are doing then seek out the advice of a seasoned builder before proceeding.*

Dongle-based Internet connection and web mail

Dear editor
Some areas either don't have broadband or it's slow. As you know, a compromise (and again it's area-dependent) is a third generation (3G) cellular network connection through a 'Dongle' that plugs into a USB port.

I've gone over to the 'Three' network, (finally, at last!) graduating from dial-up. No need for installing fixed wiring, modems, routers, anything mains powered. Also – of great importance to me – nothing to interfere with the HF amateur radio bands.

The capital equipment price was of the order of £20 and after that I pay £7.50 (inc VAT) each month by direct debit, no fixed-term contract so I can cancel at any time. This buys 1GB of total data traffic; more monthly capacity would be available at a higher price. With a consistent 42.2Mb/s throughput this is adequate for my present needs. These dongles are suitable for portable use, though I've got it on my fixed desk-top computer. (It works on XP.)

Now to getting rid of unwanted e-mail. This is the job of 'Mailwasher', and I still have the free version. You do need a mail service where the POP3 (incoming to you) and SMTP (outgoing from you) addresses are known. Unfortunately, BT Internet no longer accepts the anonymous bounce messages, so they have only themselves to blame for perpetuating the spam nuisance. Also, why use web mail? All the complaints I hear about email address books being hacked into are a direct result of leaving this information on the provider's server. When I say I'm still on a mail client (Outlook Express) the first reaction is that people laugh. When I point out that my address book is in my machine (including separate security back-up copies) and none of it is on BT's server, that leaves them in a more thoughtful mood. The other advantage is that you don't get force-fed adverts every time you read the mail! Again, POP3/SMTP details are essential.

Perhaps you should start a campaign in your column: boost email security – ban web mail!

Godfrey Manning G4GLM, Edgware

EPE *Online Editor Alan Winstanley replies:*
Thank you for your comments Godfrey – some routers have a USB port that allows a 3G dongle to be connected (as shown in Net Work, EPE, *May 2015 p.44). However, I can only dream of getting 3G as it is not available in my locality. A dongle is still a useful backup for individual machines especially when a BT phone line is down. For occasional use they can prove an expensive option though.*

Quite a few users, myself included, cannot get used to the idea of hosting email out there on the web, and I like to have a POP3 account, my email folder and attachments firmly under control on my hard disk. Outlook Express does what it does, but has long been susceptible to address book attacks by spammers. However, I can't talk as I persist with Eudora 7, now long obsolete and unsupported, but it's robust, lightning fast with many handy features, and runs very well on Windows 7. Some issues are creeping in with HTML email and SSL mail connections, but I intend to run it until it breaks for good, in which case finding a modern software replacement will be extremely difficult. In Net Work *April 2015 I outlined a few software and cloud-based choices for email packages.*

Theremin success

Dear editor
I thought you might be interested to see the attached pictures of my finished *Theremin* project based on the articles in *EPE*.

I had some problems following the scheme completely, largely related to the availability of some of the specified components on the UK market. You may recall we had some previous correspondence and I followed up with some discussion with Jake Rothman who helped me find some good solutions. The only availability problem I struggled to solve was the main enclosure. The UK market offered a case that was either just too small or a lot too big, so I resolved to use a wooden case from a digital radio with good results.

This also meant, unfortunately, that the template for the top cover would not fit to size and although I could stretch it using artwork software, the results gave a strange appearance so I decided to make my own.

The end result of the project from my point of view is quite pleasing and the kids will soon have their first sight… should be amusing!

Stuart Reeve, by email

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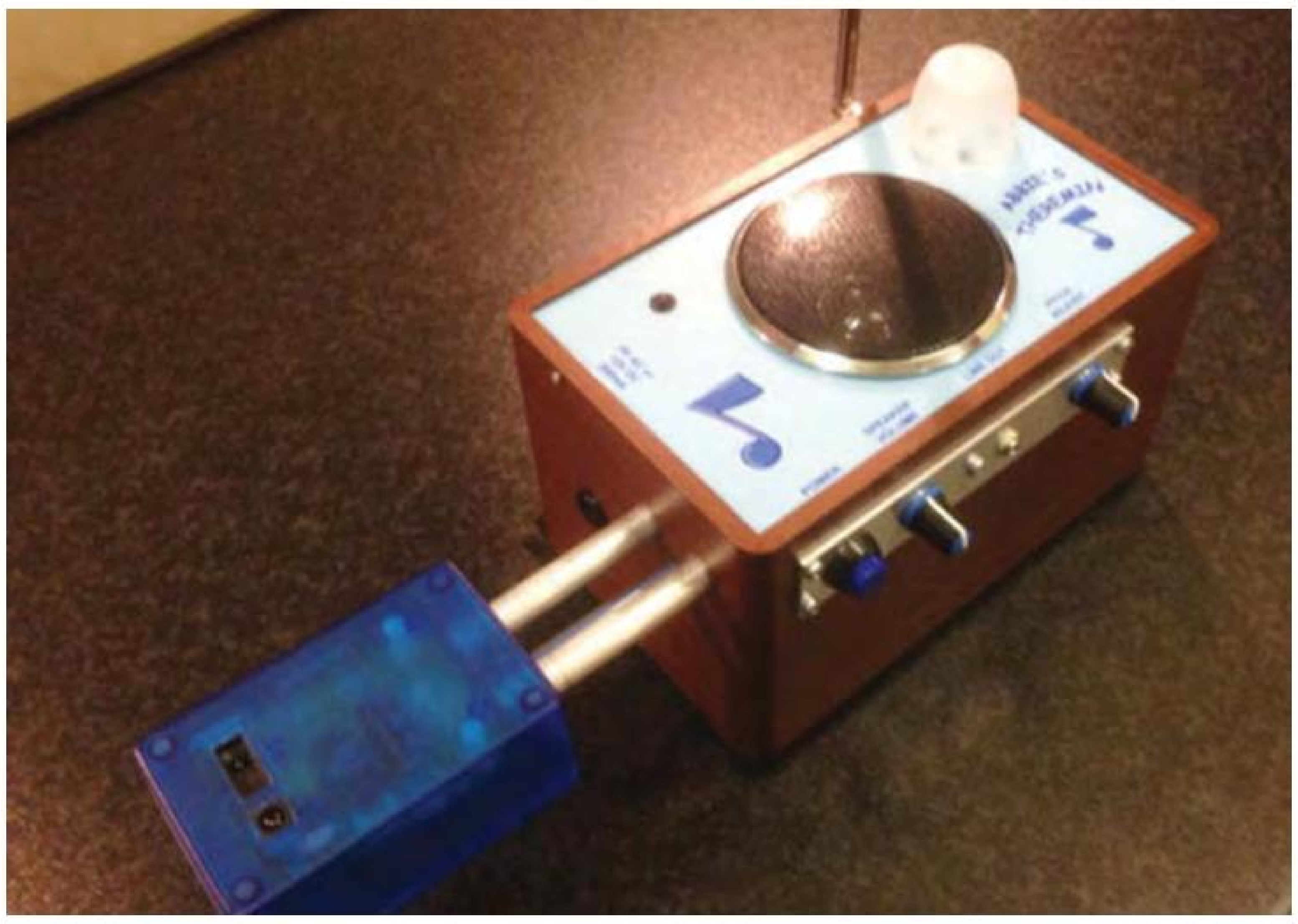

Matt Pulzer replies:
Great to see your perseverance rewarded and congratulations on your excellent cabinet making – we always enjoy seeing completed projects and strongly encourage all readers to let us see their results with photos or links to YouTube videos.

'Thank you' from Malaysia

Dear editor
I have enjoyed *EPE* for a long time – going back as far as 1965, when it was called *Practical Electronic*.

In those days of vacuum tubes, parts were difficult to come by. There was another electronic magazine fighting for my attention, but it was written in Chinese since it came from Hong Kong. This magazine normally carried one or two valve amplifiers and although I cannot read Chinese the amplifier diagrams were well illustrated.

My bedroom shelves are filled with electronic magazines and I have constructed a number of interesting *EPE* projects. I have even had help from Alan Winstanley for my school project in the mid-1990s when he wrote *Circuit Surgery*. (He said he had to get help from the professors at the University of Hull). I'd like to thank him again – I still read his great *Net Work* articles.

I am reaching my 70th birthday and would like to continue reading *EPE*, but unfortunately inflation and the weakening of the Malaysian Ringgit has caught up with my small pension. So, I'm sorry to say I have to stop my subscription – however, I will subscribe to the online version.

Finally a big 'thank you' to the entire *EPE* team that works hard to produce one of the best electronic magazines.

Tanabalan, by email

Matt Pulzer replies:
Thank you very much for your loyalty to EPE. *We are a small team, and it really means a great deal to us to hear from readers across the globe who enjoy* EPE *and appreciate the effort that goes into its publication. We hope you get as much satisfaction from reading online as you do from the printed version.*

12-digit Frequency Counter

Dear editor
I have purchased the two PCBs for the *12-digit Frequency Counter* and after spending quite a while locating all the parts I have built it. However, there is a problem with the tracks for the ADCH-80. On the PCB the designer has used pins 3 and 6, but the RFC only has connections to pins 2 and 5, so I had to link them out to get it to work.

The A input works fine, but the B input will just not work. I have fed a signal into the input and used a spectrum analyser to see the signal coming out of the prescaler section from IC4 into Q1, but it will just not display a frequency.

Are you aware of any other errors on the PCB before I have to tear the whole thing apart and start again.

Nigel Jones, by email

Nicholas Vinen replies:
It sounds like you may have the ADCH-80+ instead of the ADCH-80A+ specified in the parts list. It has a different pinout, but is otherwise identical. This can be worked around by simply bridging the pins (2/3 and 5/6). This has happened to a number of people because if you search the Mini-Circuits website for ADCH-80A+ it's the ADCH-80+ which comes up first – very annoying!

As far as I know, the PCB is correct – something like 100 have been built using the same design and we've had virtually no complaints.

I'm assuming that you're switching to Channel B using the front panel and the associated LED is lighting up. When Channel B is selected, pin 9 of IC13 should go high and pin 5 should go low. This changes which signal is being fed to IC12b. After IC12b, the counter circuitry is common for both channels, so assuming the signals from IC4's outputs are correct, that just leaves the differential-to-single-ended circuit using Q1/Q2 and IC13 as being the possible sources of problems.

I would use a frequency counter which can count up to a few MHz (many DMMs are suitable) to check the signal at pin 8 of IC13 when channel B is selected. It should be 1/1000th the frequency of what's being fed into the channel B input. If that's no good, look for the signal at pin 9 of IC13. If it's there then there's a problem with the control logic, if not then I'm suspicious of Q1/Q2. Check that these are the right type, installed correctly and possibly try replacing them as one may be faulty.

Ideally, it would be nice to use a scope to check that the differential signals from pins 6 and 7 of IC4 are in anti-phase and of the correct amplitude and frequency; however, obviously not everybody has a scope and can do this check. If the signal from Q1's collector is still no good after checking/replacing Q1 and Q2 then there's something wrong with the channel B divider chain, but it's hard to say where exactly without a scope. Lacking one, I would just have a very good look at all the SMD components, especially their orientations and soldering.

PE CHAMP still going strong!

Dear editor
I recently came across editions of *EPE* from 2014 in which Alan Winstanley looked back on 50 years of your magazine. This took me back to the 1970s when I first became interested in electronics and became a regular subscriber to *Practical Electronics* (*PE*) and *Everyday Electronics* (*EE*). I moved to South Africa in 1980 and am retired here now, but wanted to let you know that I still have a working *PE CHAMP* that I built in 1978! I only made the processor board, but learnt 4040 machine code from your articles and wrote several program for this machine. Every now and again I carefully take it from its storage box and I'm always surprised when the Sinclair display lights up and lets me know it's still alive.

A family and work life got in the way of my hobby for many years, but now that I am retired I am getting back into electronic projects, and now potter away in my garage with the soldering iron. I have nearly all the copies of both *PE* and *EE* from 1975 to 1980, and they still provide me with enjoyable projects to build. In fact, I am now using the *Teach-In* articles of *EE* to get my grand-children interested.

I hope your magazines carry on for a long time to come, and thank you for the pleasure they have given me.

Tom Smales, Ramsgate, KZN, South Africa

Matt Pulzer replies:
Alan's retrospective was very popular and we are delighted you enjoyed reading it. Good luck enthusing the grandchildren – I hope the current series of Arduino-based Teach-In *will appeal to them.*

Looking for a 6V CDI

Dear editor
I read with interest you recent *High-Energy Multi-Spark CDI for Performance Cars* project. I would like to build a CDI (capacitor discharge ignition) to run an Ariel Arrow two-stroke twin-cylinder motor bike engine. Unfortunately, it only produces 6V DC, so I wondered if there is any mod you could suggest to run the project on this voltage.

Stuart Williams, by email

Matt Pulzer replies:
Only one of our CDI designs is suitable for a 6V supply – the Replacement CDI for Small Petrol Motors *may suit your bike if there is a high voltage generator included on the bike itself. Jaycar offers a kit:*

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Max's Cool Beans

By Max The Magnificent

Cunning coding tips and tricks

As you may recall, I'm using NeoPixel rings (tri-coloured LEDs) in a lot of my current projects. For example, I'm using a 16-element ring to illuminate the antique vacuum tube mounted on top of my *Vetinari Clock*, as shown in this video: **http://bit.ly/195JKWR**

Often, I want to have a pixel racing round and round the ring, which involves turning a new pixel on and turning the previous pixel off, and then repeating the process for each subsequent pixel. A small problem occurs at the beginning of each cycle (or the end, depending on your point of view). One solution is to include an additional test in the control loop (two tests if you want to rotate the pixel both clockwise and anticlockwise), but I consider this to be a little messy. An alternative trick is to use a bitwise & (Boolean AND) operation, which removes the need for any tests. All of this was discussed in my previous column on this topic – see *EPE*, January 2016.

However, there is a slight 'gotcha' to using the bitwise & approach; it only works when you are playing with rings that have 2^n elements; eg, 2^2 = 4, 2^3 = 8, and 2^4 = 16. But what can we do if our rings don't contain 2^n elements? Take my *Capriciously Cunning Chronograph* project, for example (Fig.1).

In this case, we have 60 elements in the outermost ring, 24 elements in the center ring, and 12 elements in the inner ring, which means that none on these little scamps boasts 2^n elements. This is a bit of a poser, but fortunately there is a solution...

Cross-reference arrays to the rescue

For the purposes of these discussions, and for the sake of simplicity, let's assume we're dealing with rings containing only five elements as illustrated in Fig. 2.

Let's also assume we wish to have one pixel chasing itself round and round the ring in a clockwise direction, what we would ideally like to do would be to call the following snippet of code over and over again:

```
for (i = 0; i < 5; i++) {
  ring.setPixelColor(i,255,0,0);
  ring.setPixelColor((i-1),0,0,0);
  ring.show();
  delay(100);
}
```

Remember that when we instantiate our NeoPixels and call them `ring` and specify five elements, this creates an array called `ring[]` containing five elements numbered 0 to 4, where each element comprises three 8-bit fields to hold the R, G, and B colour values. So, the idea here is that we are lighting up pixel `i` (where `255, 0, 0` means the red sub-pixel is fully on and the green and blue sub-pixels are off) and we turn off pixel `i - 1`. As we know, the above

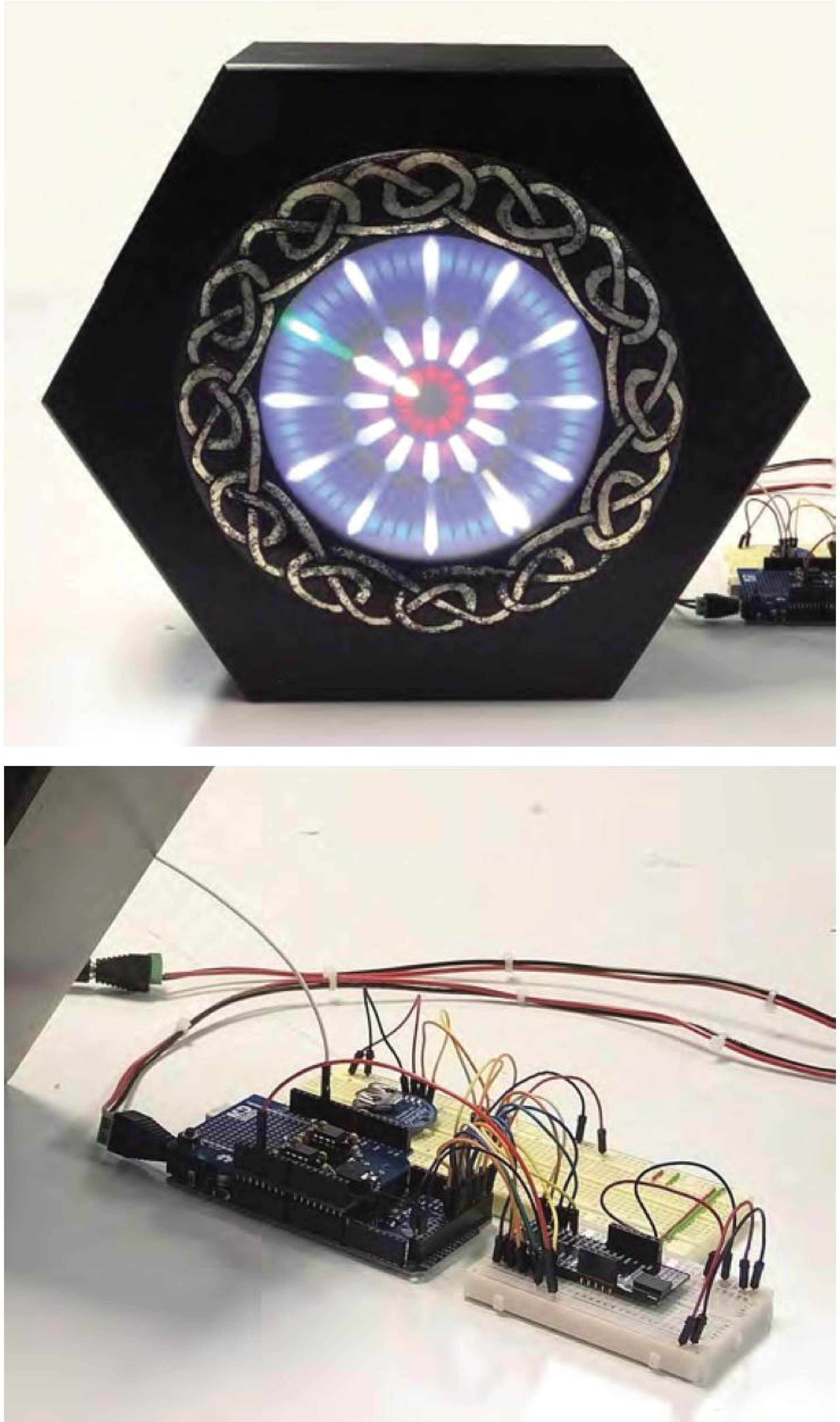

Fig.1. There are three electronic boards. Front left, Arduino Mega with my own custom audio spectrum analyser shield on top. Large breadboard at the back, ChronoDot Real-Time Clock (RTC) – this is going to be joined by a temperature/pressure sensor and a 9DOF (nine degrees of freedom 3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer) sensor – all of these will be mounted on a single custom shield. Small breadboard front right, the Simblee module described in last month's Hot Beans *column. This allows me to control the clock via Bluetooth using my iPad – this is going to be mounted on a prototyping shield. So, in total we'll have an Arduino Mega plus three Shields, plus a power supply, plus other stuff – all of which will be mounted in the cabinet*

code won't actually work as we wish because we're going to run into problems when `i = 0`. In this non-2^n element case, we know that our bitwise & solution won't work (draw out the table of `i` *vs* `i - 1` values like we did in the previous article if you aren't sure why). We could always return to using a special test for the `i = 0` case, but we don't like doing that because it's 'messy.' The solution I prefer is to use a cross reference array as follows:

```
byte xRef[6] = {4,0,1,2,3,4};

for (i = 1; i < 6; i++) {
  ring.setPixelColor(xRef[i],255,0,0);
  ring.setPixelColor(xRef[i-1],0,0,0);
  ring.show();
  delay(100);
}
```

(Do note in the above, if something is in red I am drawing attention to it – it represents a change from previous code.) Observe that we've added an extra value at the beginning of this array (4); also that we've replaced `(i = 0; i < 5; i++)` in our `for` loop with `(i = 1; i < 6; i++)`; also that we've replaced direct references to `i` with calls to our `xRef` (cross-reference) table.

The point is that we no longer have a problem with the initial case, because when we are lighting up element `i = 1` (which is cross-referenced to element 0 in our NeoPixel ring), we are turning off element `i - 1 = 0` (which is cross-referenced to element 4 in our NeoPixel ring).

But what happens if we also wish to have the ability to make our pixel chase itself round and round the ring in an anticlockwise direction? Well, in this case, we can add an extra element onto the end of the array as illustrated in the following code snippet:

```
byte xRef[7] = {4,0,1,2,3,4,0};

for (i = 5; i >= 0; i--) {
  ring.setPixelColor(xRef[i],255,0,0);
  ring.setPixelColor(xRef[i+1],0,0,0);
  ring.show();
  delay(100);
}
```

A sticky situation

There's another reason I like using cross-reference arrays, because they often get me out of a sticky situation. Let's suppose that we create some gadget or gizmo and we insert a 5-element NeoPixel ring oriented as illustrated in Fig.2, with element 0 presented on top. Now suppose that we have to replace our ring for some reason – maybe we zap it with an electrostatic discharge or something.

Suppose that, for one reason or another, we mistakenly orient our new ring as illustrated in Fig. 3 (the green element numbers indicate what we want/expect; the red numbers reflect what we've actually got). Actually, this sort of thing happens more often than you might expect. Sometimes your new ring is one element off, or it may be that the elements are actually numbered in the reverse order to what you expected. It's even worse if you superglue the little scamp in before you check things out (…don't ask!).

Now, if all we are doing is having one pixel race round and round the ring, then such a miss-orientation really doesn't matter. All that will happen is that the pixel will commence its rotation from a new starting point, but after one revolution we will never notice the difference.

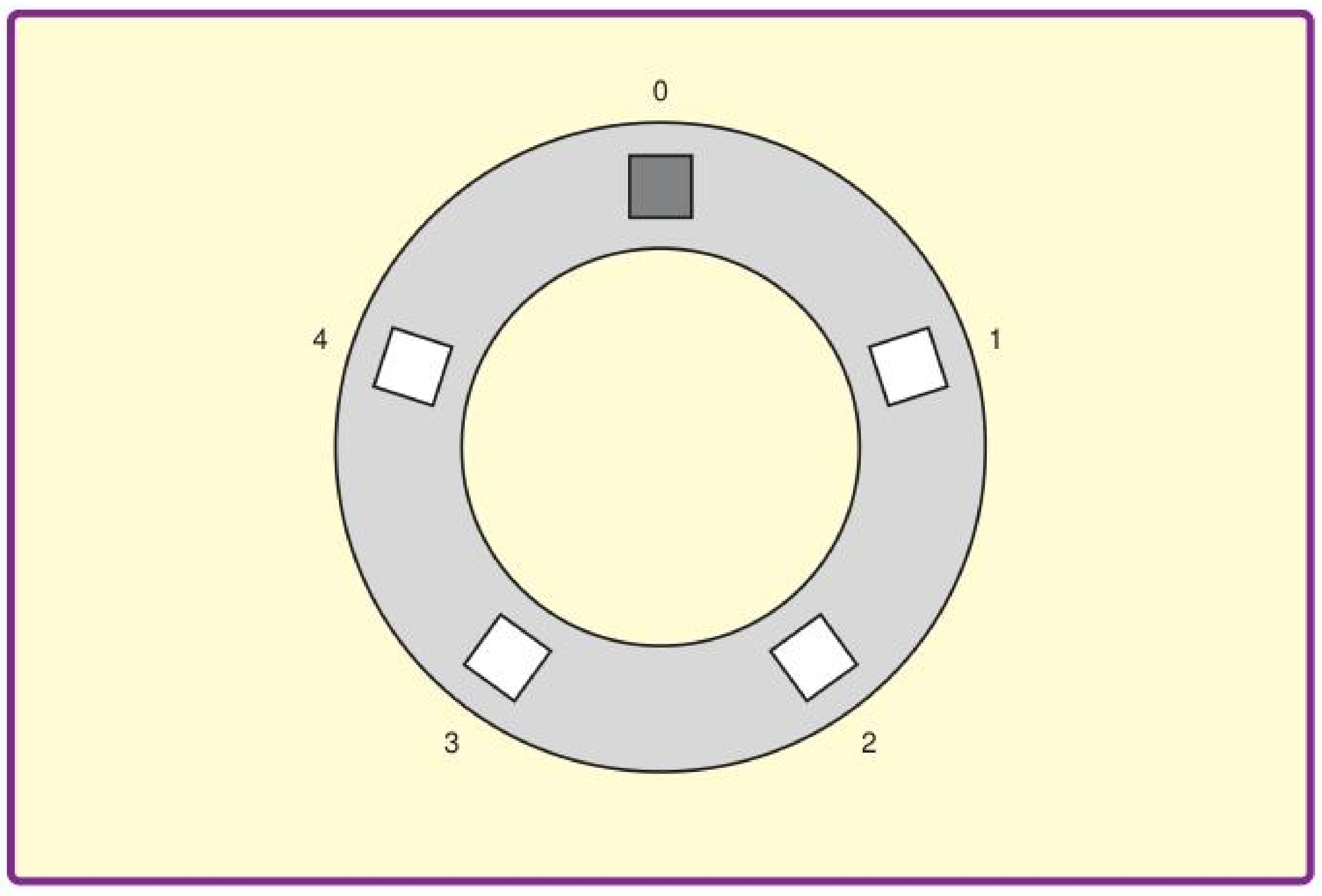

Fig.2. A 5-element ring

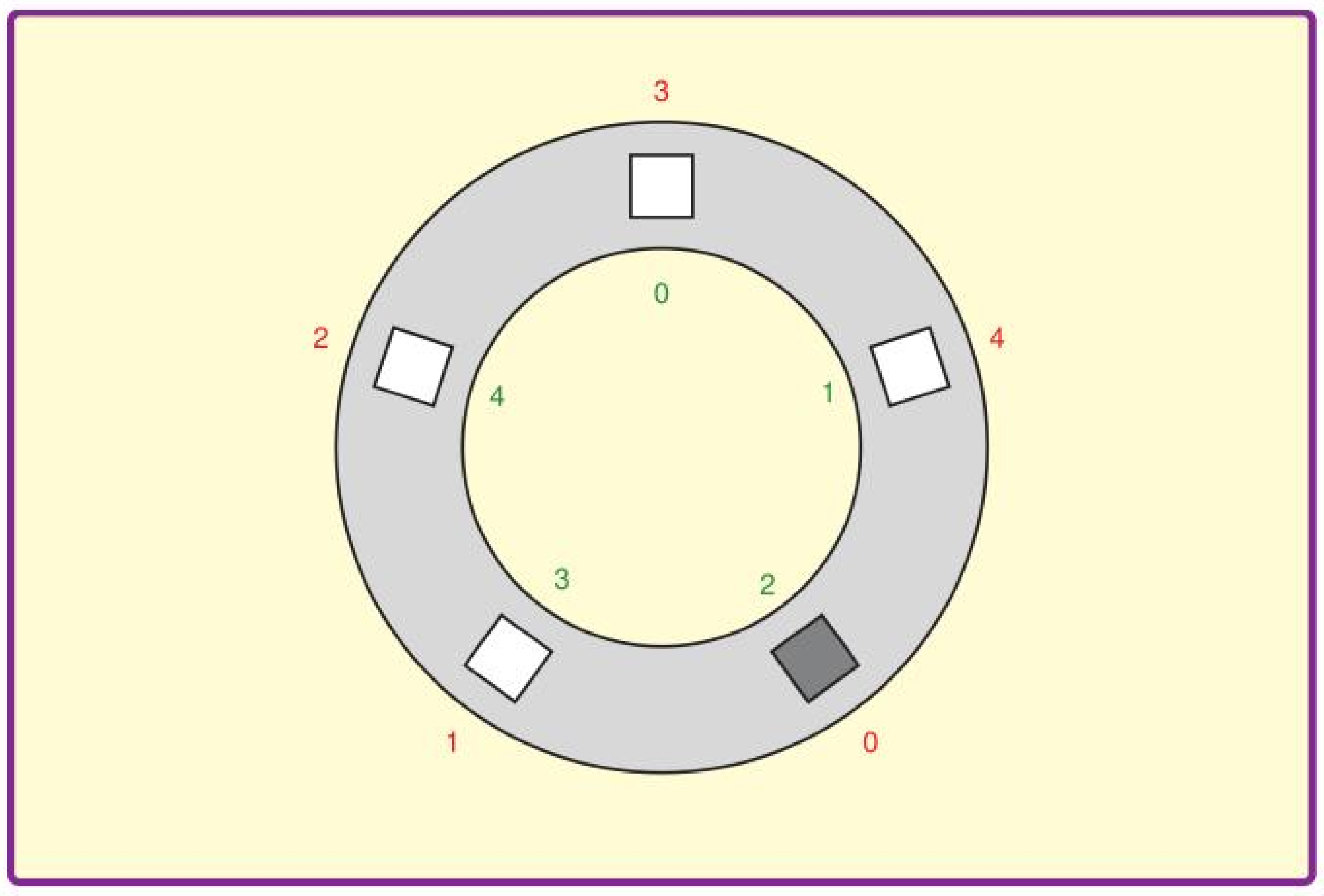

Fig.3. A miss-oriented ring

On the other hand, suppose that we turn individual pixels on and off from multiple places in our code. For example, suppose we have a statement like this buried somewhere deep in our code:

```
ring.setPixelColor(i,255,0,0);
```

In this case, having to locate and update this, and similar, statements could potentially be very time-consuming and error prone.

However, if we originally had a cross-reference array that was geared up to our original ring's orientation (Fig.2.) like the following:

```
byte xRef[7] = {4,0,1,2,3,4,0};
```

Then all we have to do is update this array's contents to reflect our new ring's orientation (Fig.3.) and everything else in the program can remain as is:

```
byte xRef[7] = {2,3,4,0,1,2,3};
```

But what if...

The various approaches we've discussed thus far will handle a lot of simple usage models, but they start to fall down a bit when we want to implement more sophisticated usage scenarios. What we need is a cunning plan; indeed, a plan so cunning we could pin a tail on it and call it a weasel. Happily, we have the very plan at our fingertips... as we will discuss in my next column. Until then, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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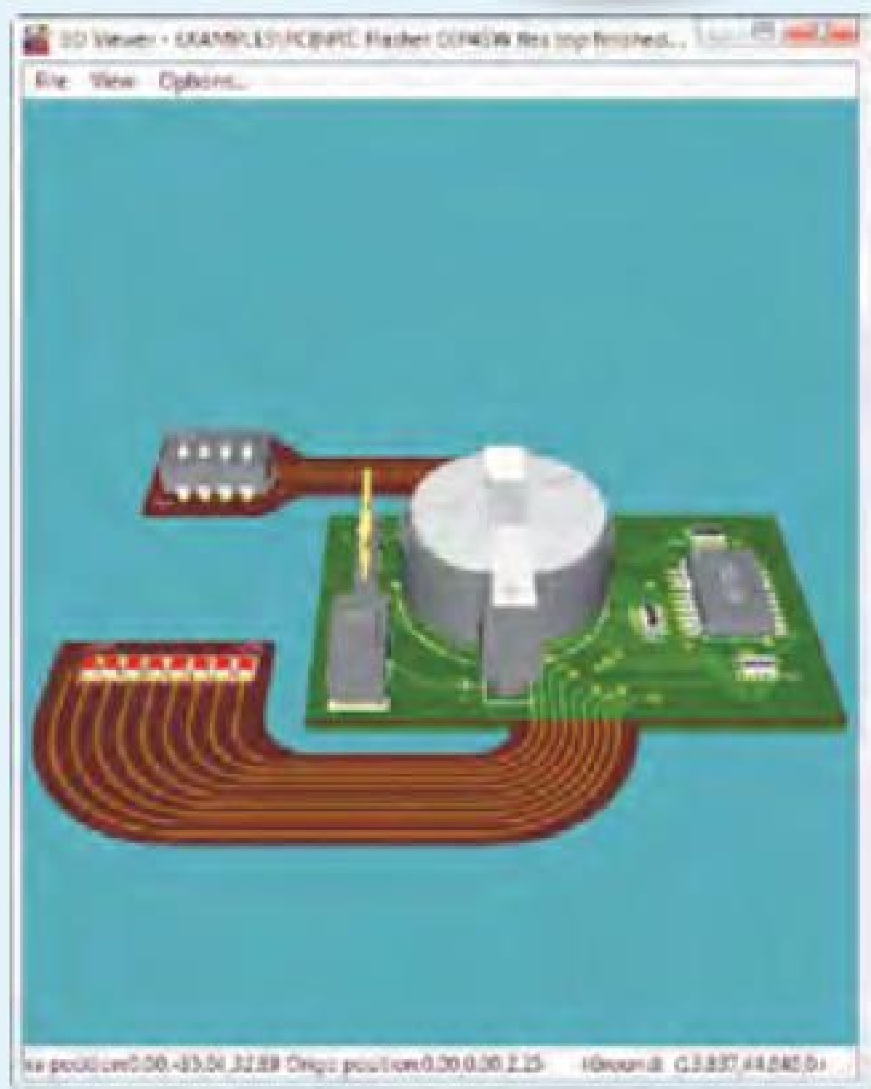

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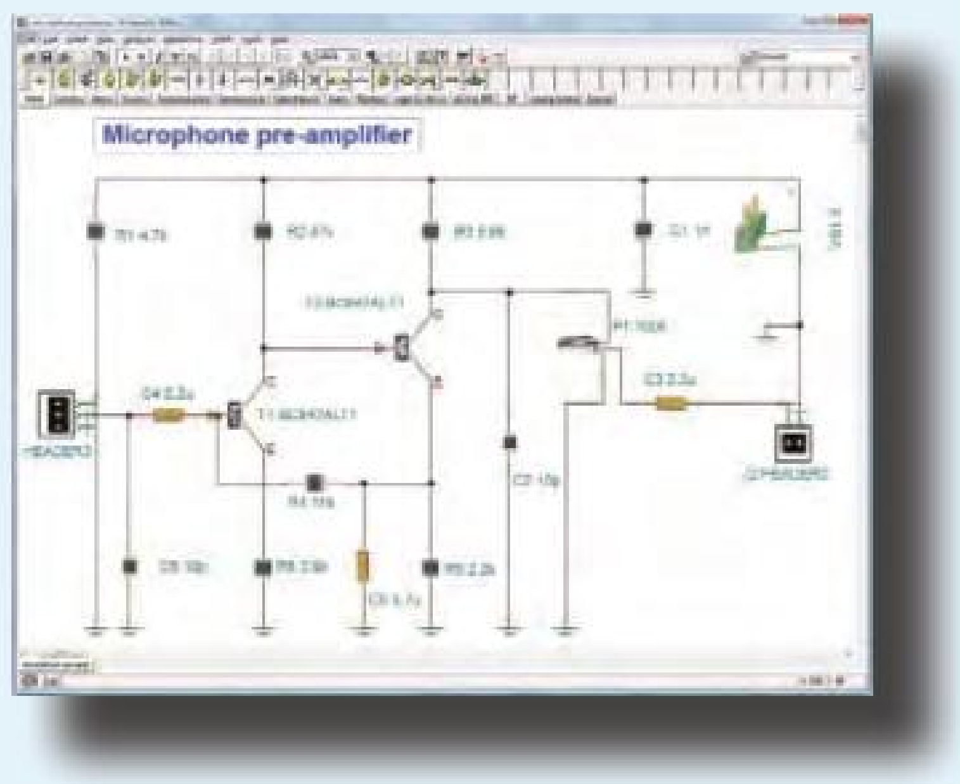

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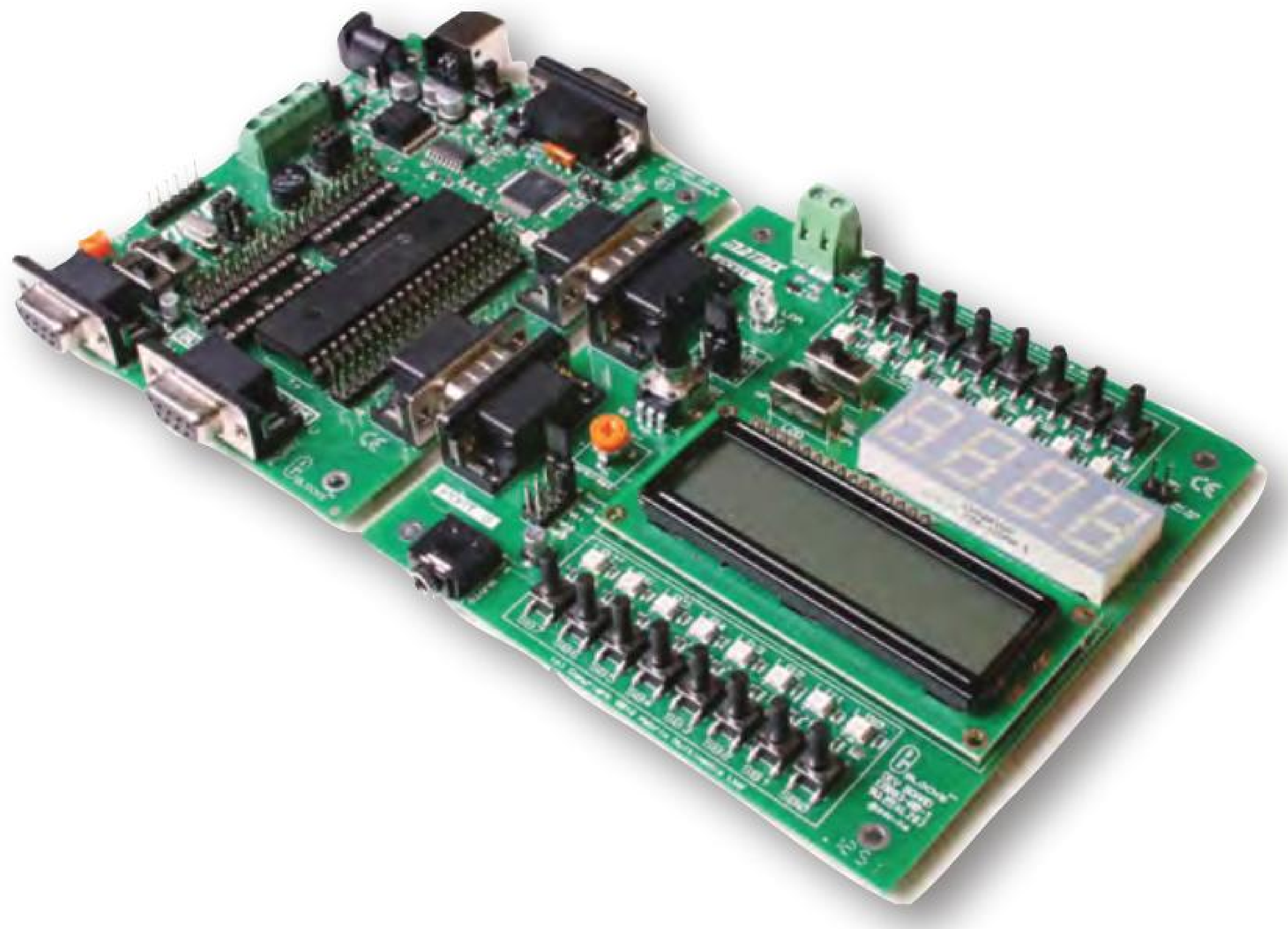

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(Formerly PICtutor)

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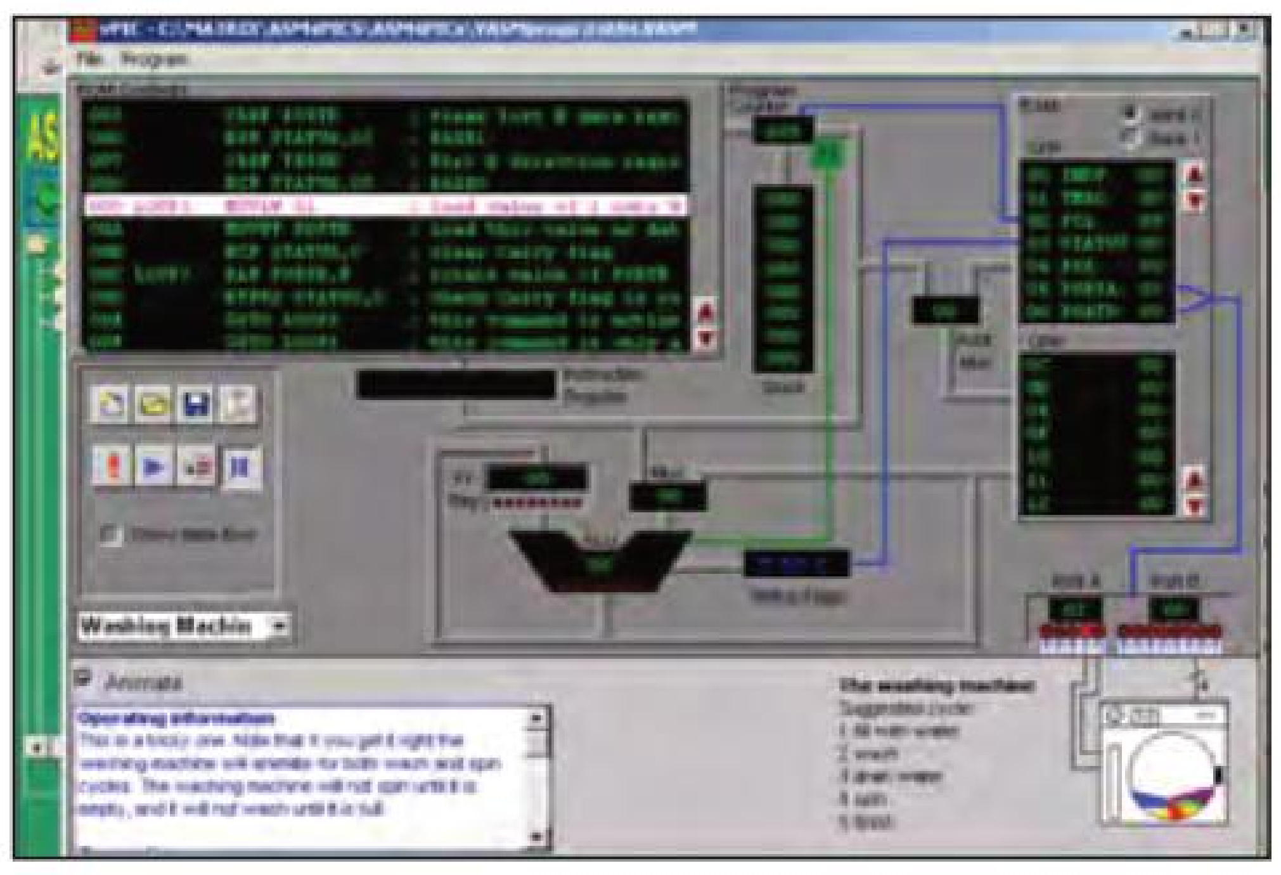

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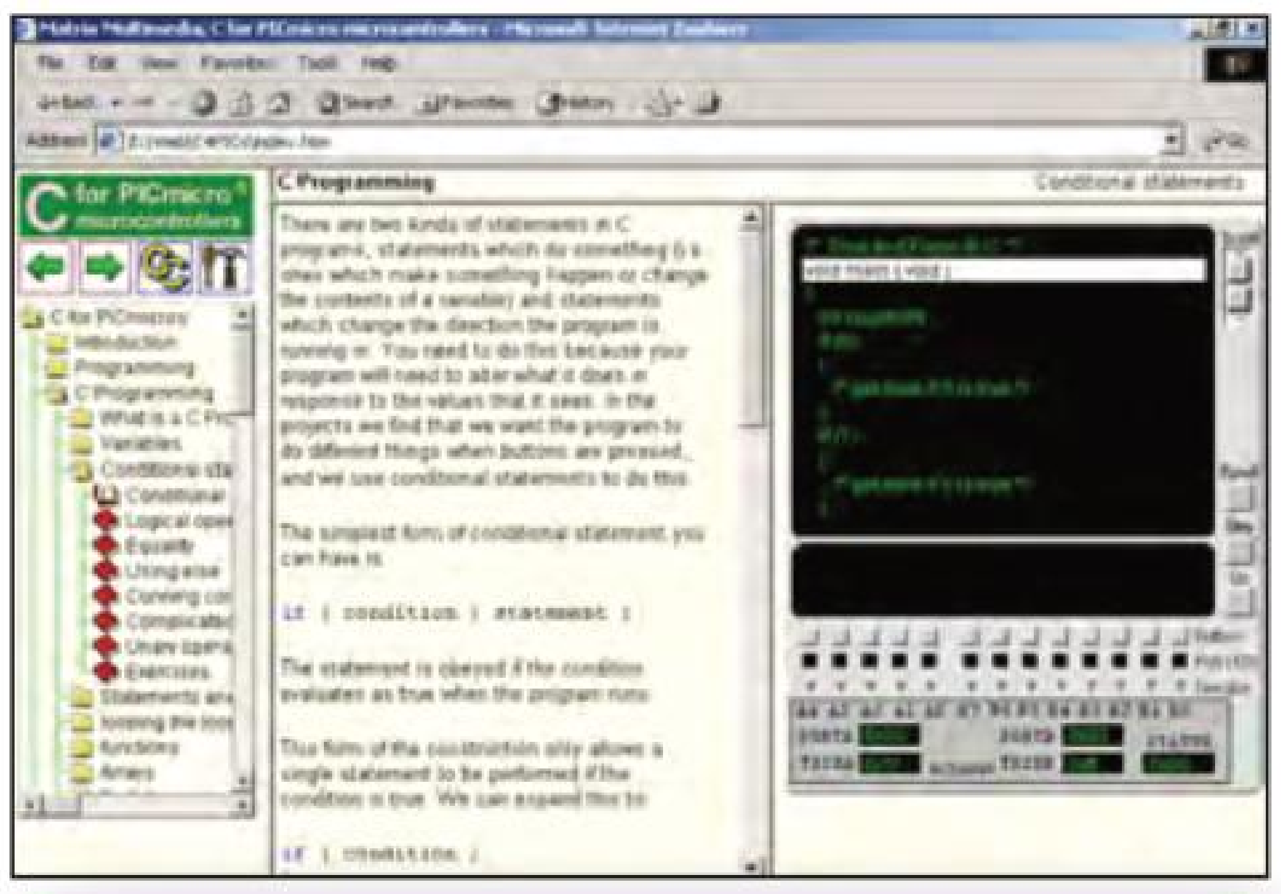

Minimum system requirements for these items: Pentium PC running, 2000, ME, XP; CD-ROM drive; 64MB RAM; 10MB hard disk space.
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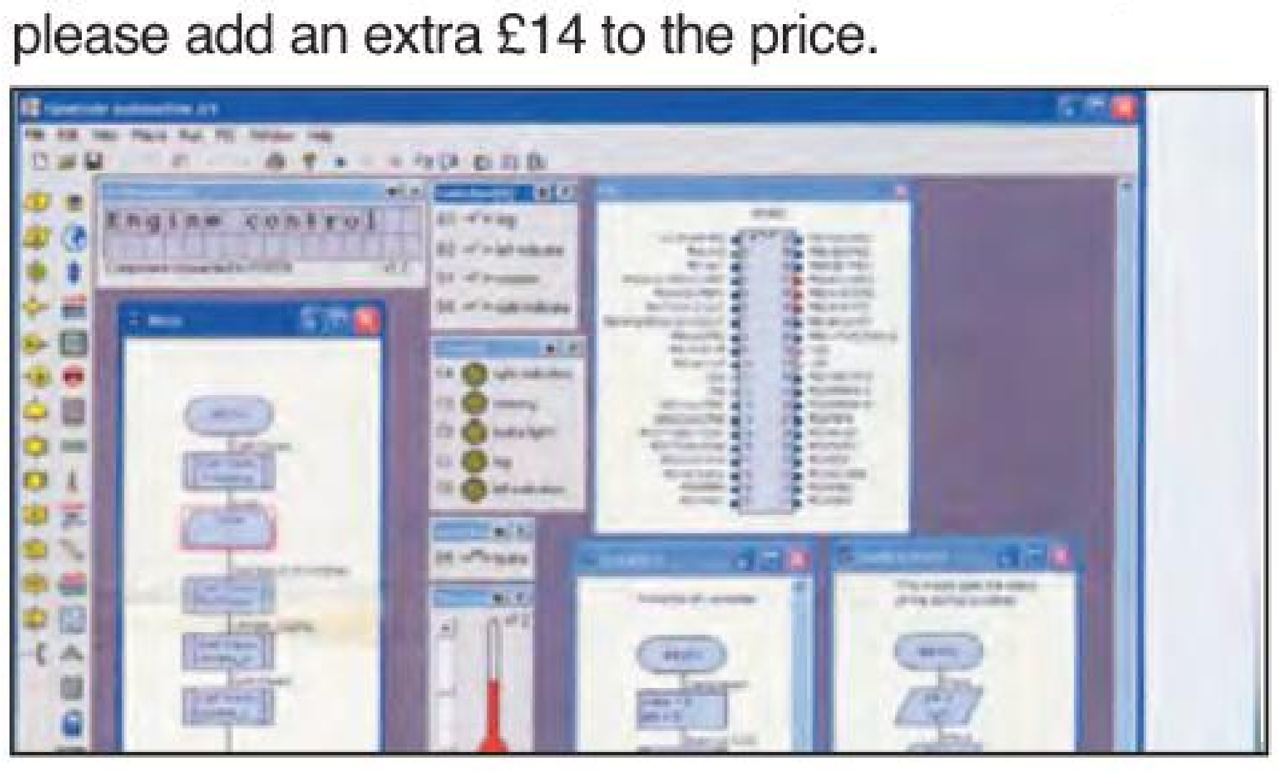

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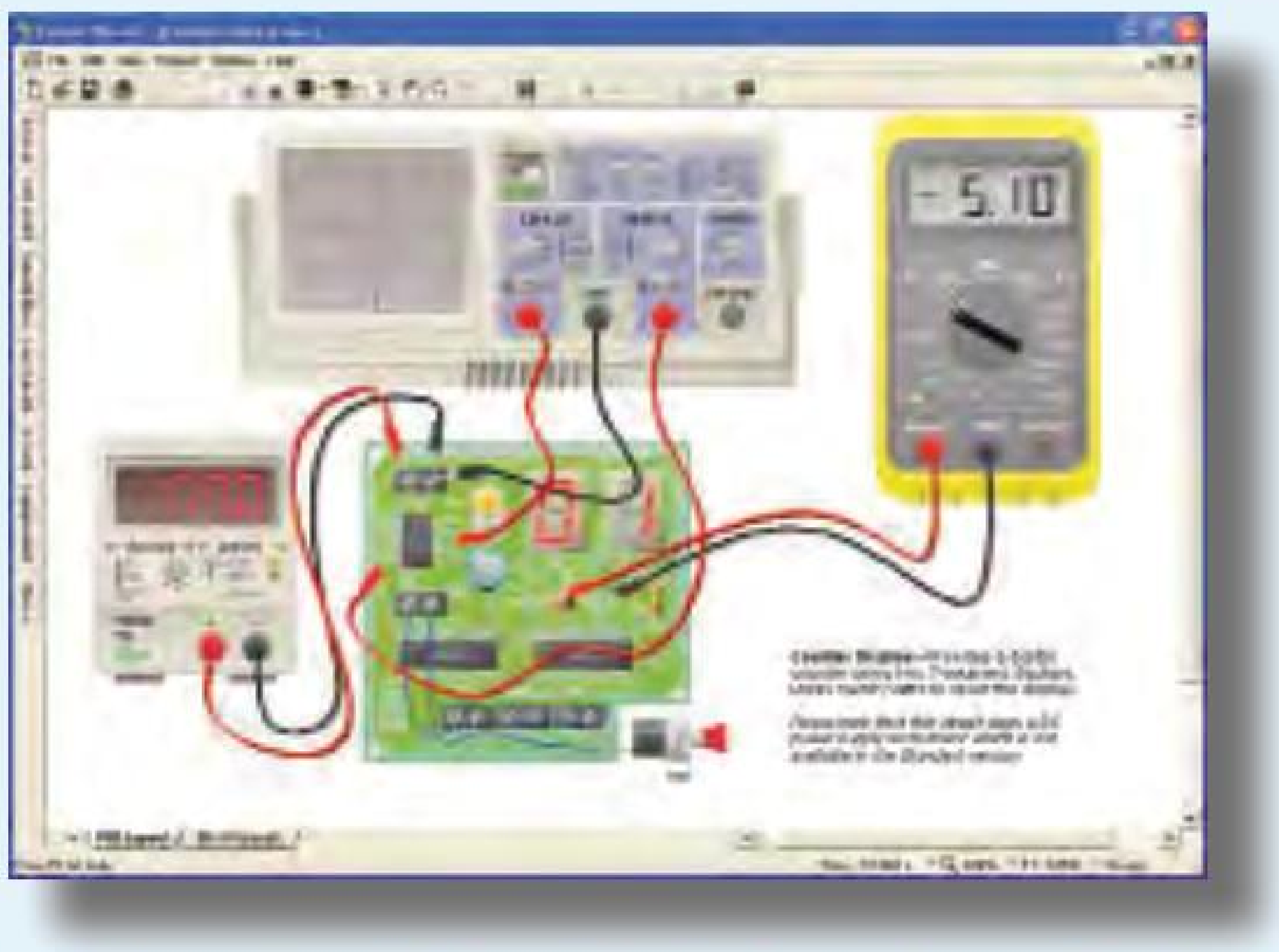

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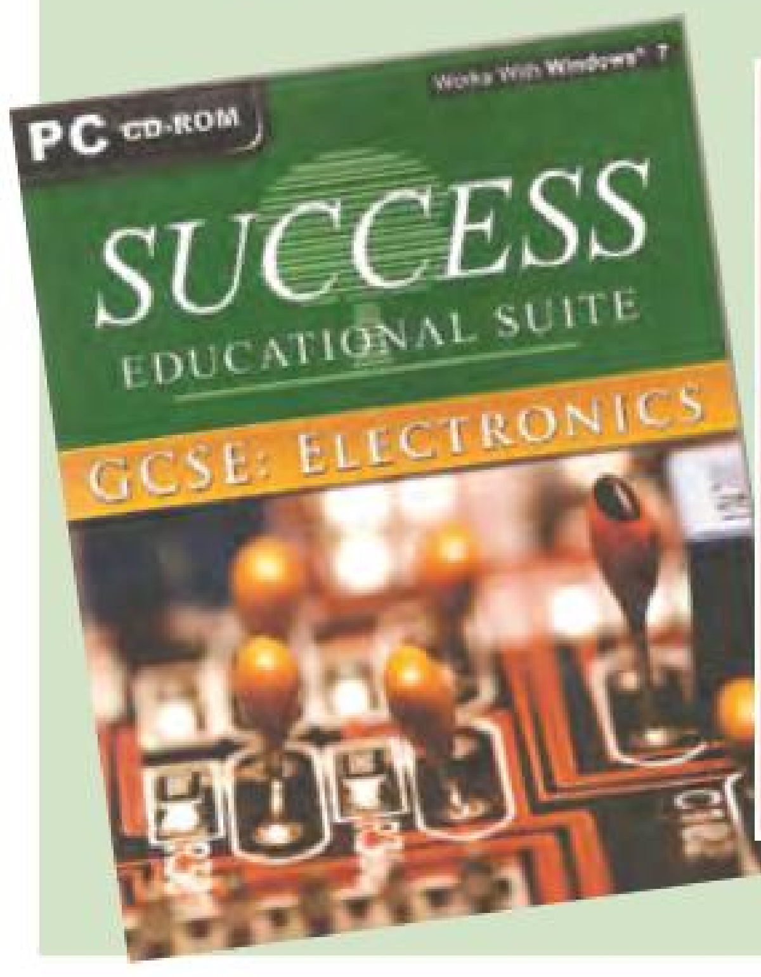

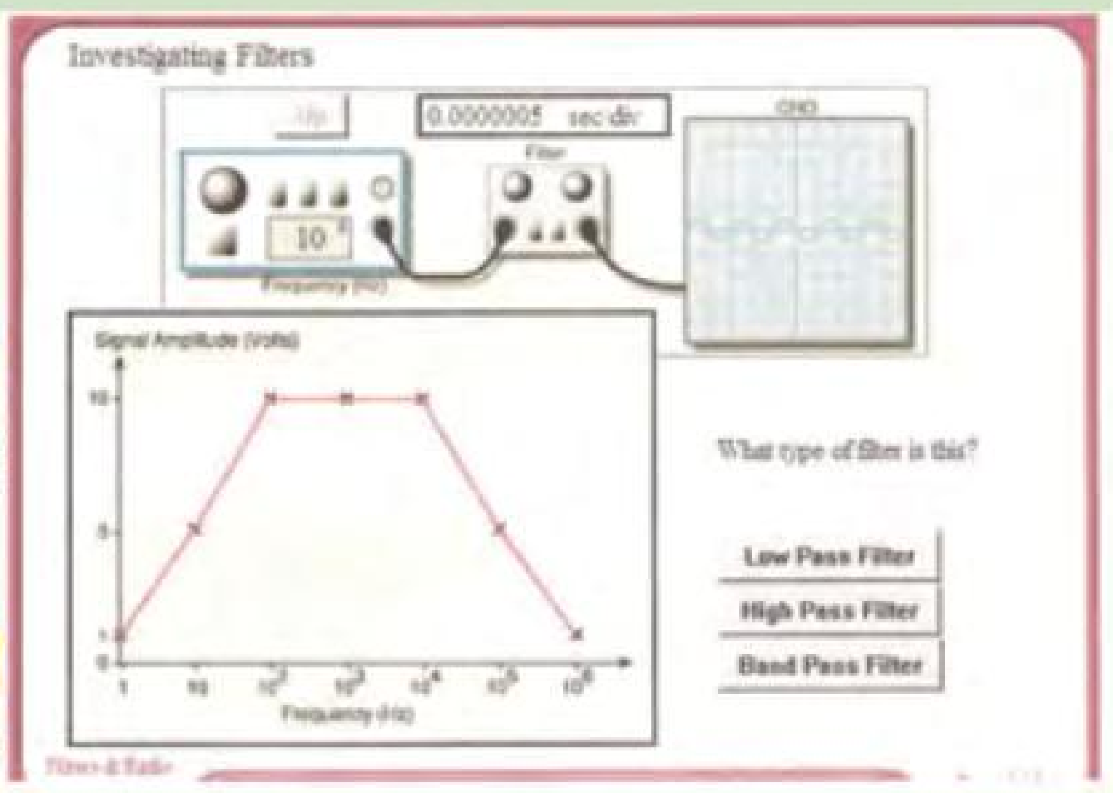

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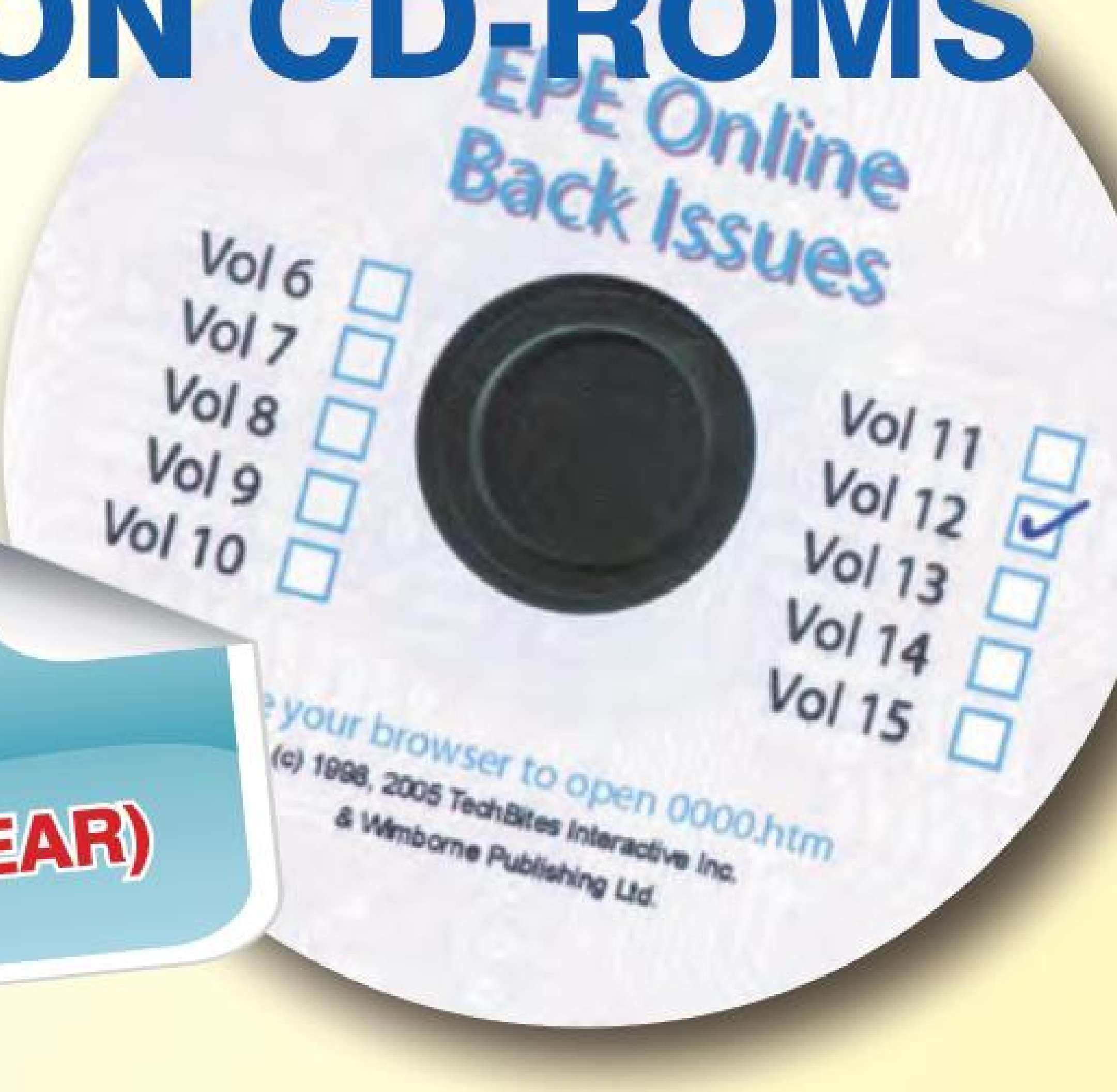

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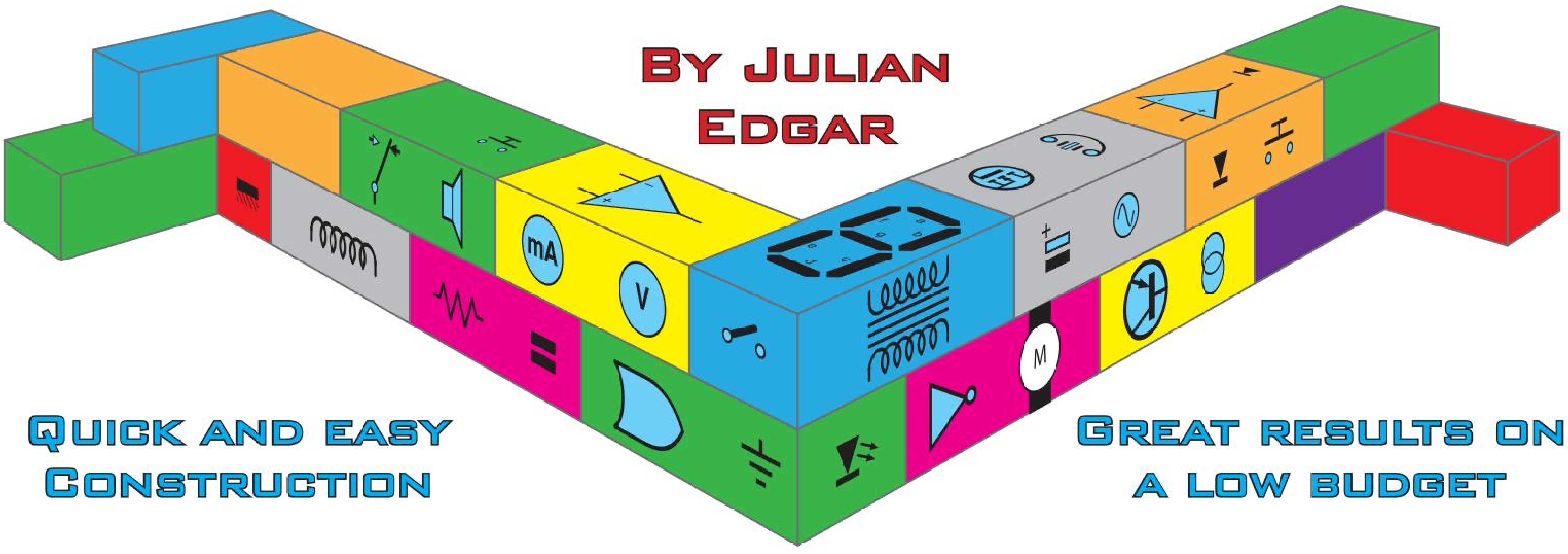


BY JULIAN EDGAR

QUICK AND EASY CONSTRUCTION

GREAT RESULTS ON A LOW BUDGET

ULTRA-LOW-CURRENT LED FLASHER

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be… FAST! These projects range from around £15 to under a fiver… bargains!

Ultra-low-current LED flasher

Here's a project that ticks all the boxes – it costs nearly nothing, is very easy to build, and is extremely useful. So what is it? It's an ultra low current LED flasher – but what use is that?

Well, if you need to have a 'power on' indicator on battery-operated equipment, this LED will consume far less power than a conventional LED. That way, the 'on' indicator is contributing only fractionally to flattening the battery.

Or take an indicator that needs to provide a security warning – like the flasher now fitted to many car dashboards or door cappings. Again, the requirement is for an indicator that takes very little current.

Wherever you want to be able to find a camping lantern in a dark tent – just fit this flasher and you'll always know where it is. And you can leave it flashing all night without taking any more than a tiny current draw from the battery.

So, whatever warnings or indicators are needed, or if your requirement is for a flashing LED that can operate in a low-power environment, here is the LED flasher that you want. And best of all, it will take you only a few minutes to build and should cost virtually nothing in parts!

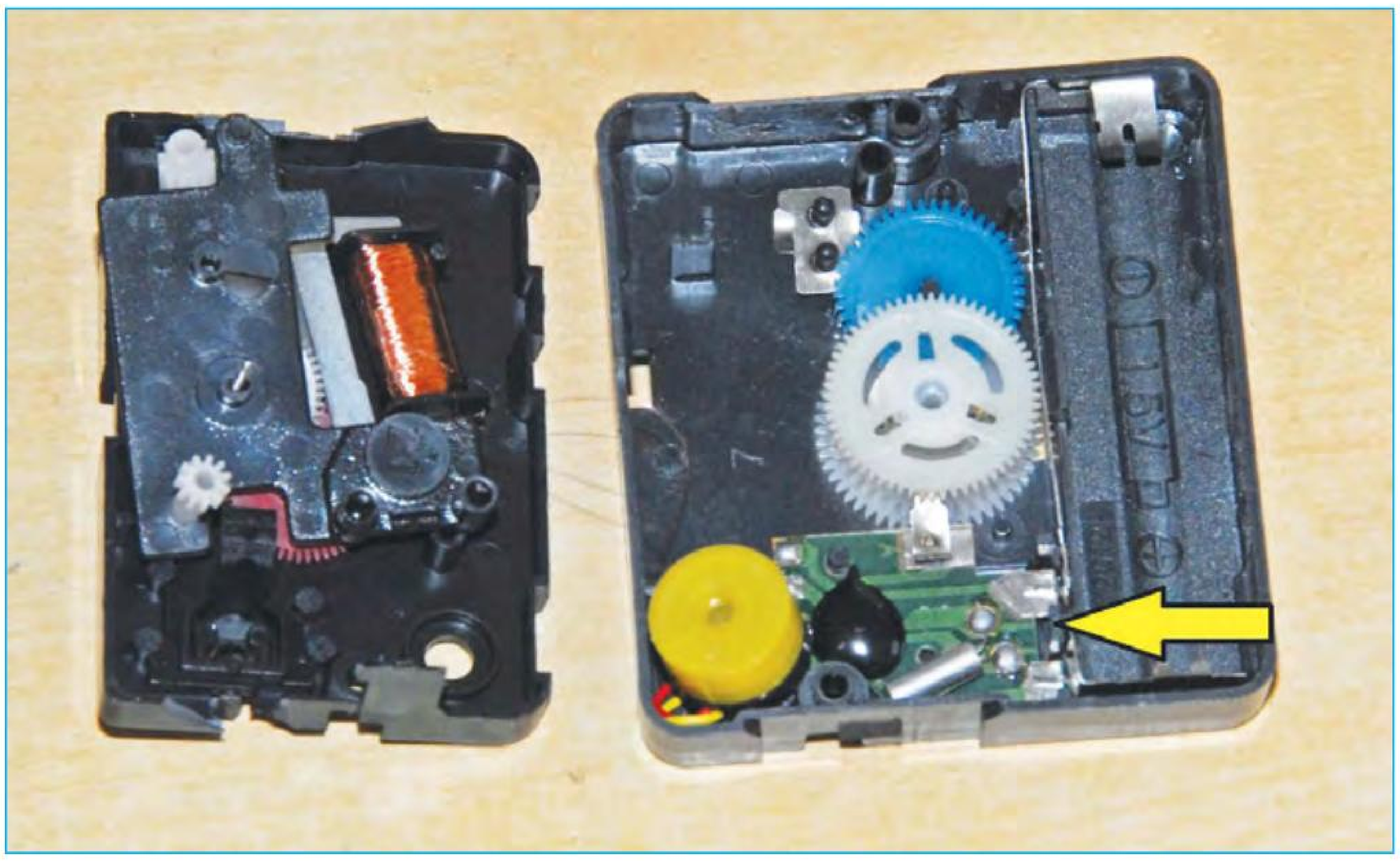


Fig.2. The clock's guts – disassemble the clock until you can remove the circuit board (arrowed). Before you do so, take special note of the polarity of the battery connections and which solder pads connect to the solenoid coil

Fig.1. Any small battery-powered clock can be used as the basis of this project. You can buy them new very cheaply or salvage the workings from a discarded clock

How long will it keep flashing?

So, just how long will the *Ultra-low-current LED* operate? I can't tell you – I have just about given up waiting for the battery in the test unit to go flat.

I rigged up a clock module and LED with a couple of alkaline AA cells I had lying around. They were certainly not new – I think their combined voltage was about 2.9V. I started the LED flashing and then left it to its own devices, working 24 hours a day.

After a week, it was still flashing happily. After another week – so over 330 hours – it was still going. And the battery voltage? It had dropped only 0.1V to 2.8V.

Given that a new pair of AA cells will give a voltage of about 3.2V, you can see that it is very likely that with new batteries, the LED would flash for months. Fit two D-cells and it may well flash for years. I told you it was low current!

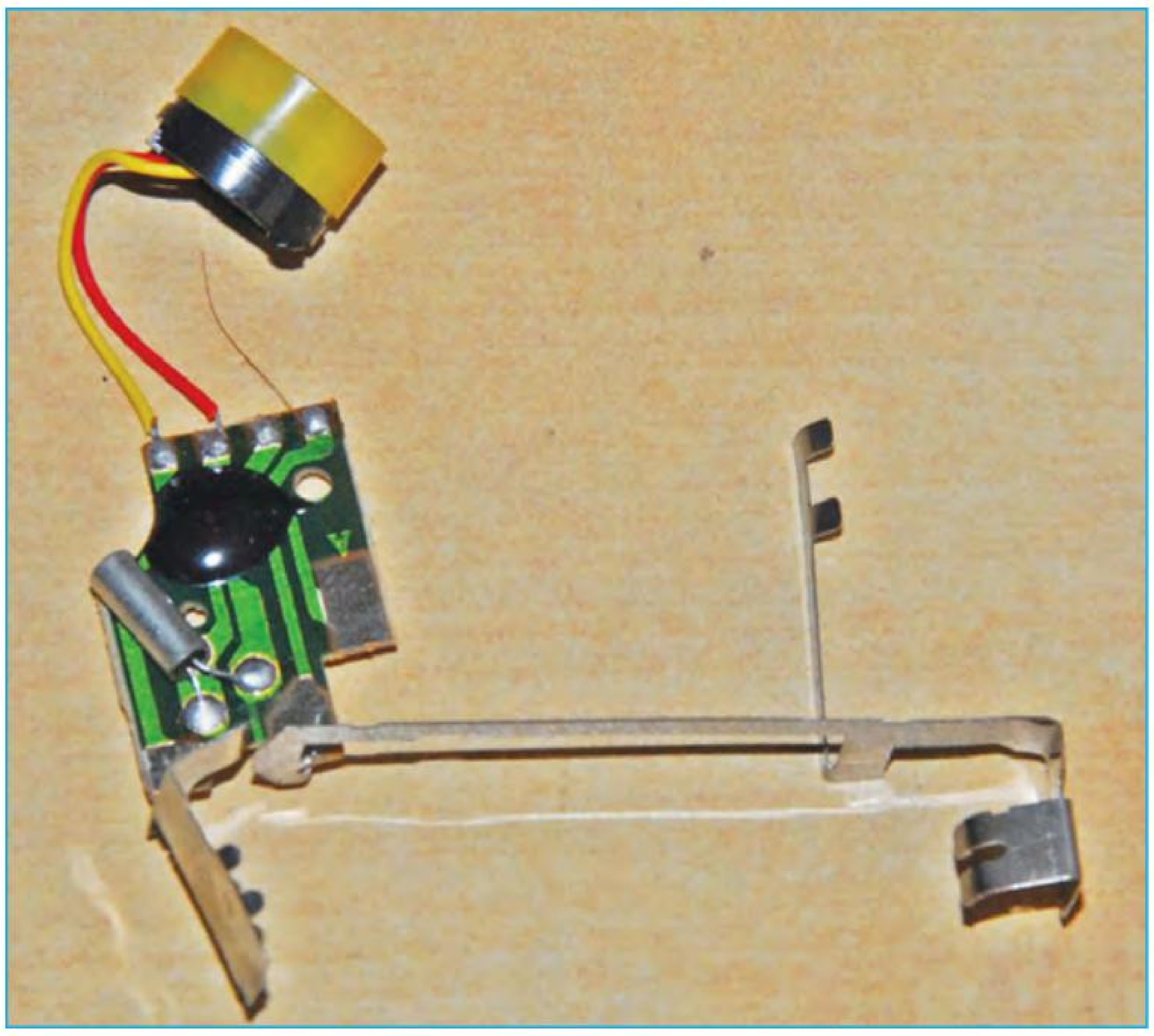


Fig.4. Connect 3V to the original power terminals (use the correct polarity!) and solder an LED directly across the solenoid coil outputs. Use flexible thin insulated wire for these connections

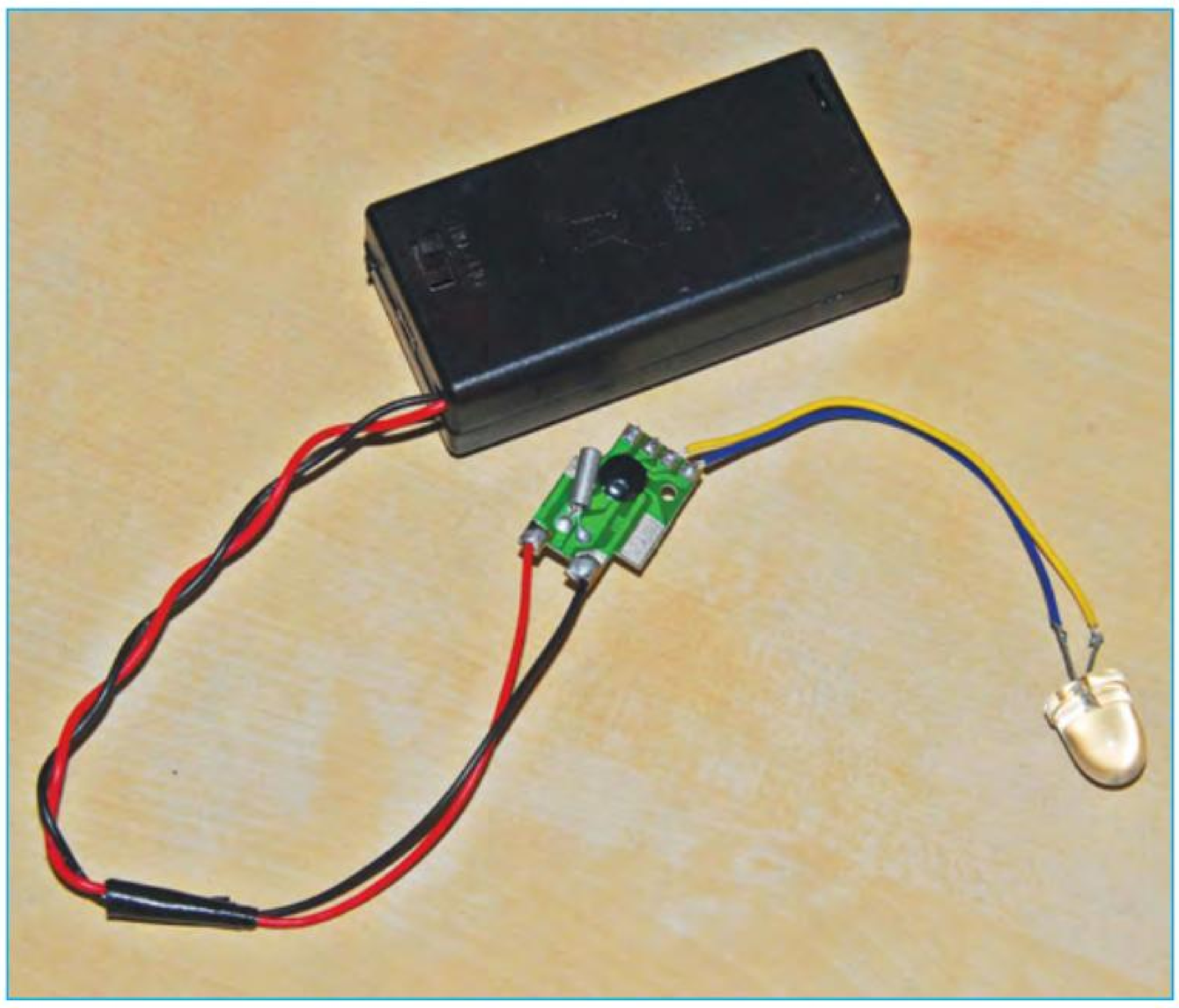


Fig.5. The completed LED flasher, ready for mounting in a box. The flasher will operate continuously for many weeks on a pair of alkaline AA cells. Used as a 'power on' indicator in battery-operated equipment, it draws only the tiniest of currents

The building block

The circuit board for this project is taken straight from a battery-operated clock. You can buy one new on-line for just a few pounds (and that includes delivery) or purchase one from a high street discount/Pound store. Or, you may simply have an old battery-operated clock that you can recycle.

Remove the circuit board from within the clock module. Carefully study (1) the polarity of the power connections to the board, and (2) the connections for the external solenoid coil that powers the clock mechanism. Many small alarm clocks also have a remote piezo buzzer – you don't need this, so remove it by snipping its wires.

Now it's time to make this module into a flasher. Simply connect a high intensity LED to the solder pads that once went to the solenoid coil. Then connect a 3V source to the power connections, observing the original polarity.

LED connection

It doesn't matter which way you connect the LED, and despite the clock originally being powered by 1.5V, it will work fine on 3V. But hold on! 'It doesn't matter which way you connect the LED' – how can that possibly be so?!

The clock module outputs a pulse every second – one is negative-going and the other positive-going. The LED lights only when its connection polarity matches the direction of the pulse. Furthermore, because the pulse is so short and the internal current source appears limited, you can drive pretty well any high intensity LED directly from the output without using a current-limiting resistor. (If you are worried by that, you can of course insert a series resistor.)

Flashing

The LED will flash once every two seconds with a 31ms (millisecond) pulse – a duty cycle of just 1.56 per cent. (At a measured 20mA current, you can now see why battery life is so long!) If you want a faster flash rate, just parallel another LED in reversed polarity to the first. The LEDs will flash alternately, an LED lighting once per second. You can also use two different colour LEDs – for example, you can have a green/red flasher.

Be very careful when soldering to the board. Always use small diameter flexible wires rather than solid-cored copper (as is used on the LED leads). If you don't use flexible wires, it's very easy to lift the solder pads off the board by bumping the connection.

The LED you use can be as large as the 10mm design used here, or as small as a 3mm unit. If you want a prominent warning, use a 10mm LED and cover it in a tube of semi-translucent plastic – I used the cap from a thick marker pen.

Fig.6. A coloured cap from a marker pen can be used over the LED to give a more diffused glow

School project

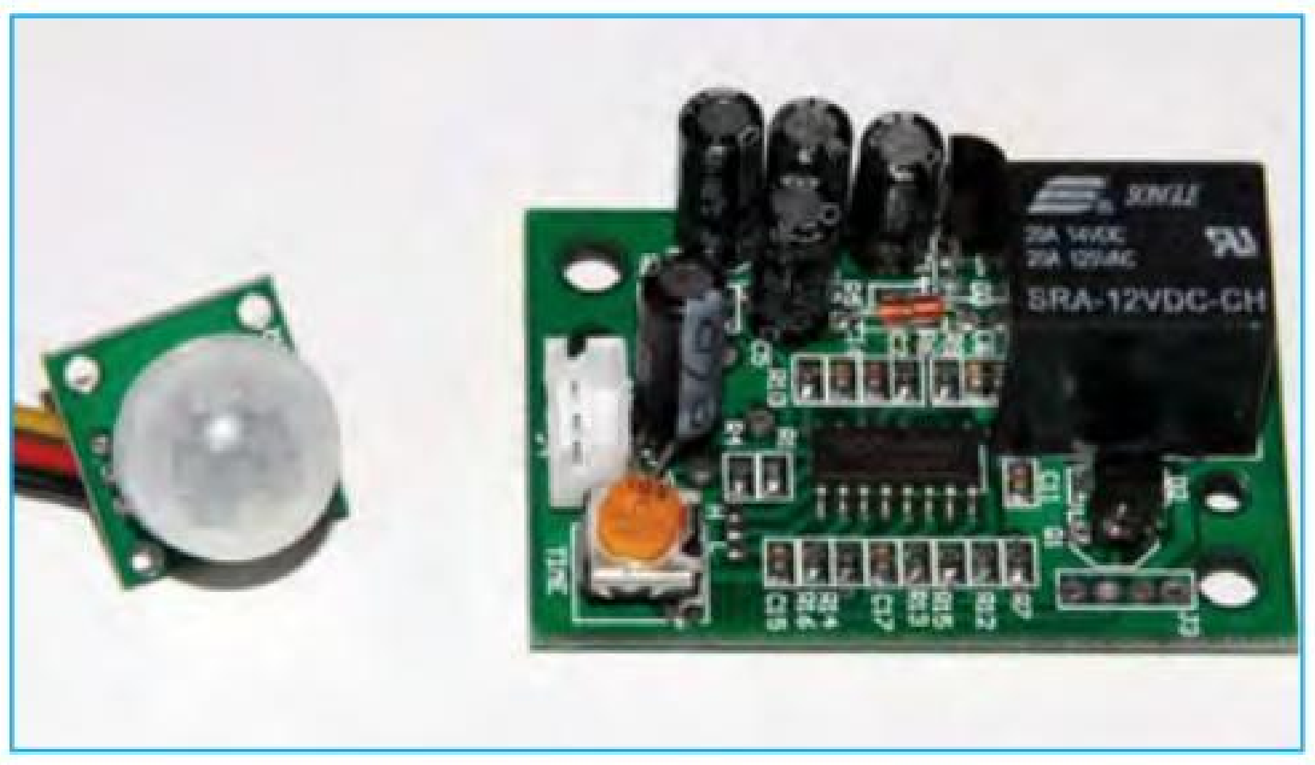
This is a project that's great for a beginner in electronics – especially in schools with access to an oscilloscope. (A scope? Try measuring: the length of the pulse, what polarity does it have, how frequently does it occur, and – more trickily – how much current does the LED draw?)

Conclusion

It's a great project, and in my household, where everyone can see the 'test' LED flasher happily beavering away, it's become a conversation piece; 'when will the battery finally give up the ghost?', everyone asks. Anywhere you need a low-current 'power on' indicator or warning, it's perfect.

Next month

Here's another great project based on an off-the-shelf module that ticks all the boxes – a *PIR Sensor Module* with an adjustable relay output. All this is in our next super *Electronic Building Block* article.



Next month – build this handy PIR Sensor Module *with relay output*

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

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Next Month

Content may be subject to change

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Clip
Operate/Low Battery

Low Frequency Distortion Analyser

Are you concerned about the quality of your 50Hz 230VAC mains supply? Would you like to measure the harmonic distortion of your loudspeaker system? This unit will measure the distortion of a 50Hz/60Hz mains waveform (via an isolating transformer) or the distortion of any 3-20V sinewave signal over 20Hz-10kHz – for example, the output of a midrange or bass loudspeaker.

Appliance Insulation Tester
Silicon Chip

Appliance Insulation Tester

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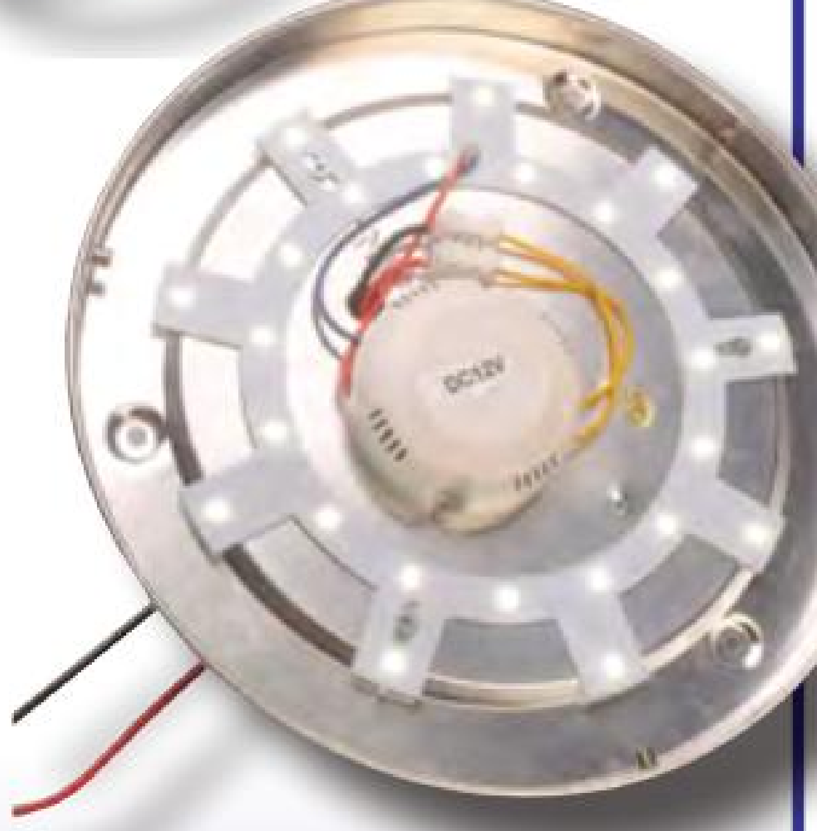

Teach-In 2016 – Part 3

In March's *Teach-In 2016* we will look at displays and keyboards that can be used with the Arduino. We'll cover interfacing an alphanumeric LCD display; keypads and buttons; and in our programming feature, *Coding Quickstart*, we'll introduce strings and their manipulation. Finally, *Get Real* will show you how to build a simple entry/access control system.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks, PIC n' Mix* and *Net Work.*

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Published on approximately the first Thursday of each month by Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Printed in England by Acorn Web Offset Ltd., Normanton, WF6 1TW. Distributed by Seymour, 86 Newman St., London W1T 3EX. Subscriptions INLAND: £23.50 (6 months); £43.00 (12 months); £79.50 (2 years). EUROPE: airmail service, £27.00 (6 months); £50.00 (12 months); £95.00 (2 years). REST OF THE WORLD: airmail service, £37.00 (6 months); £70.00 (12 months); £135.00 (2 years). Payments payable to "Everyday Practical Electronics'', Subs Dept, Wimborne Publishing Ltd. Email: subs@epemag.wimborne.co.uk. EVERYDAY PRACTICAL ELECTRONICS is sold subject to the following conditions, namely that it shall not, without the written consent of the Publishers first having been given, be lent, resold, hired out or otherwise disposed of by way of Trade at more than the recommended selling price shown on the cover, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of Trade or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.

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